APPENDIX D

ETHANOL FUEL TRANSPORTATION AND DISTRIBUTION

NREL Notes

Appendix D: Ethanol Fuel Transportation and Distribution

Most of the data presented in this appendix underwent substantial revision before it was employed in the fuel cycle analyses presented in *Fuel Cycle Evaluations of Biomass Ethanol and Reformulation Gasoline, Volume I, Summary Report*. There were two major types of alterations. First, the authors of this appendix reported incremental differences between neat ethanol (pure) and reformulated gasoline. This approach assumes that differences in inputs and environmental releases are linear (e.g., between E100, E95 and E10) and can be added to the distribution inventory for reformulated gasoline to estimate emission inventories for E10 and E95. This approach does not adequately characterize the fuel cycle characteristics associated with the fuels under scrutiny (E10 and E95) because of regional distribution characteristics and differences in the characteristics of the fuels. The reformulated gasoline distribution characteristics were based on national distribution data, while the characteristics of E10 and E95 were site specific for five identified locations. The site-specific characteristics for each fuel were not reported separately, but were aggregated together as a national total. Since six site-specific fuel cycles were the goal of the study, the assumptions for E10 and E95 were applied to the site-specific distribution characteristics of the six locations.

Parameters for E10 and E95 were used to recalculate input and output characteristics associated with distribution of these two fuels using equations provided in this appendix. These parameters and the calculations are shown on the follow pages. They are presented without explanation, since the text of the appendix describes in detail the source and use of the equations used. In the process of recalculating the environmental characteristics of ethanol fuel distribution, several other minor changes were noted. Many of the formulas reported in this appendix used parameters for crude oil or gasoline instead of ethanol fuel parameters. These errors were corrected before this information was used. The formulas themselves, while unnecessarily complex, were ultimately correct.

Assumptions

E95, a blend of 95 percent hydrous ethanol and 5 percent reformulated gasoline, is produced at each ethanol plant, in both 2000 and 2010, and stored in railroad tank cars. It is transported by rail to bulk terminals located in major metropolitan areas in each of the six ethanol fuel cycles. The portion of fuel that is delivered to each bulk terminal is a function of the population of the city relative to the population of the entire surrounding area. That fraction is then applied to the production of E95 from the ethanol facility to determine how much E95 is shipped by rail to each major metropolitan area. For the 2000 case, all the E95 is shipped to the Chicago area. The storage tanks used to store E95 are dedicated to that purpose to avoid fuel contamination. In addition, the use of dedicated storage tanks increases fuel turnover in the tank and affects vapor losses as shown in the following calculations.

For the 2010 fuel cycles, the E95 is trucked from the bulk terminal, located in each major metropolitan city, to the retailers in the surrounding area. For the E10 fuel cycle (2000), the E95 is blended with reformulated gasoline at the bulk terminal and E10 is distributed by truck to retailers throughout the Chicago area. Truck and rail transportation emissions are calculated separately from vapor loss emissions.

Parameters and Calculations

The following pages presents the new parameters and calculations that replace those reported in Appendix D. The equations are taken directly from Appendix D. Please read Appendix D for further information.

Peoria: Calculation of ton-miles

	gallons	#/gal
Ethanol	7.82E+07	6.67E+00
Other	4.13E+06	
Total	8.23E+07	6.59E+00

Pop ratio % con	Miles	Ton Miles E100	Ton miles E95
0.0220	0.0000	0.00E+00	0.00E+00
0.5420	157.0000	2.22E+07	2.31E+07
0.1150	210.0000	6.30E+06	6.55E+06
0.0310	205.0000	1.66E+06	1.72E+06
0.0250	120.0000	7.83E+05	8.14E+05
0.0200	140.0000	7.30E+05	7.59E+05
0.0190	96.0000	4.76E+05	4.95E+05
0.0180	73.0000	3.43E+05	3.56E+05
0.0820	148.0000	3.17E+06	3.29E+06
0.1260	211.0000	6.94E+06	7.21E+06
		4.26E+07	4.43E+07

Lincoln: Calculation of ton-miles

	gallons	#/gal
Ethanol	7.80E+07	6.67E+00
Other	4.12E+06	
Total	8.21E+07	6.59E+00

Pop ratio % con	Miles	Ton Miles E100	Ton miles E95
0.0260	0.0000	0.00E+00	0.00E+00
0.2190	56.0000	3.19E+06	3.32E+06
0.1340	172.0000	6.00E+06	6.24E+06
0.0580	125.0000	1.89E+06	1.96E+06
0.1130	170.0000	5.00E+06	5.20E+06
0.3150	177.0000	1.45E+07	1.51E+07
0.0810	142.0000	2.99E+06	3.11E+06
0.0540	144.0000	2.02E+06	2.10E+06
0.0000	0.0000	0.00E+00	0.00E+00
0.0000	0.0000	0.00E+00	0.00E+00
		3.56E+07	3.70E+07

Tifton: Calculation of ton-miles

	gallons	#/gal
Ethanol	8.09E+07	6.67E+00
Other	4.28E+06	
Total	8.52E+07	6.59E+00

Pop ratio % con	Miles	Ton Miles E100	Ton miles E95
0.0080	0.0000	0.00E+00	0.00E+00
0.2550	182.0000	1.25E+07	1.30E+07
0.0700	100.0000	1.89E+06	1.96E+06
0.1020	117.0000	3.22E+06	3.35E+06
0.1070	200.0000	5.78E+06	6.01E+06
0.0850	153.0000	3.51E+06	3.65E+06
0.3240	149.0000	1.30E+07	1.35E+07
0.0490	89.0000	1.18E+06	1.22E+06
0.0000	0.0000	0.00E+00	0.00E+00
0.0000	0.0000	0.00E+00	0.00E+00
		4.11E+07	4.28E+07

Rochester: Calculation of ton-miles

	gallons	#/gal
Ethanol	8.09E+07	6.67E+00
Other	4.28E+06	
Total	8.52E+07	6.59E+00

Pop ratio % con	Miles	Ton Miles E100	Ton miles E95
0.2310	0.0000	0.00E+00	0.00E+00
0.3410	69.0000	6.35E+06	6.60E+06
0.0680	74.0000	1.36E+06	1.41E+06
0.1620	77.0000	3.37E+06	3.50E+06
0.1140	150.0000	4.61E+06	4.80E+06
0.0840	170.0000	3.85E+06	4.01E+06
0.0000	0.0000	0.00E+00	0.00E+00
0.0000	0.0000	0.00E+00	0.00E+00
0.0000	0.0000	0.00E+00	0.00E+00
0.0000	0.0000	0.00E+00	0.00E+00
		1.95E+07	2.03E+07

Portland: Calculation of ton-miles

	gallons	#/gal
Ethanol	8.09E+07	6.67E+00
Other	4.28E+06	
Total	8.52E+07	6.59E+00

Pop ratio % con	Miles	Ton Miles E100	Ton miles E95
0.3150	0.0000	0.00E+00	0.00E+00
0.0770	42.0000	8.73E+05	9.07E+05
0.1360	123.0000	4.51E+06	4.69E+06
0.4250	172.0000	1.97E+07	2.05E+07
0.0470	187.0000	2.37E+06	2.47E+06
0.0000	0.0000	0.00E+00	0.00E+00
0.0000	0.0000	0.00E+00	0.00E+00
0.0000	0.0000	0.00E+00	0.00E+00
0.0000	0.0000	0.00E+00	0.00E+00
0.0000	0.0000	0.00E+00	0.00E+00
		2.75E+07	2.86E+07

Rail ton miles - E100

Location	Btu/tmi	ton-mi	throughput	btu/Thput	hp-hr/MMBtu	btu/hp-h	k constant	hp-hr/kBtu	Gal Diesel
Rail/Chicago	497	3.34E+07	6.82E+07	75700	3.22E-03	2544.4	1.00E+09	1265.37	1.29E+05
Rail/Peoria	497	4.26E+07	7.82E+07	75700	3.58E-03	2544.4	1.00E+09	1405.33	1.64E+05
Rail/Lincoln	497	3.56E+07	7.80E+07	75700	3.00E-03	2544.4	1.00E+09	1177.61	1.37E+05
Rail/Portland	497	2.75E+07	7.43E+07	75700	2.43E-03	2544.4	1.00E+09	954.61	1.06E+05
Rail/Tifton	497	4.11E+07	8.09E+07	75700	3.34E-03	2544.4	1.00E+09	1311.74	1.59E+05
Rail/Rochester	497	1.95E+07	7.82E+07	75700	1.64E-03	2544.4	1.00E+09	644.87	7.55E+04
Total average 2000	497	3.34E+07	6.82E+07	75700	3.22E-03	2544.4	1.00E+09	1265.37	1.29E+05
Total average 2010	497	1.66E+08	3.90E+08	75700	2.80E-03	2544.4	1.00E+09	1101.71	1.28E+05

Rail ton miles - E95

Location		Btu/tmi	ton-mi	throughput	btu/Thput	hp-hr/MMBtu	btu/hp-h	k constant	hp-hr/kBtu	Gal Diesel
Rail/Chicago	E95	497	3.48E+07	7.18E+07	77730	3.10E-03	2544.4	1.00E+09	1216.92	1.34E+05
Rail/Peoria	E95	497	4.43E+07	8.23E+07	77730	3.44E-03	2544.4	1.00E+09	1352.01	1.71E+05
Rail/Lincoln	E95	497	3.70E+07	8.21E+07	77730	2.88E-03	2544.4	1.00E+09	1132.52	1.43E+05
Rail/Portland	E95	497	2.86E+07	7.82E+07	77730	2.34E-03	2544.4	1.00E+09	918.42	1.10E+05
Rail/Tifton	E95	497	4.28E+07	8.52E+07	77730	3.21E-03	2544.4	1.00E+09	1261.21	1.65E+05
Rail/Rochester	E95	497	2.03E+07	8.23E+07	77730	1.58E-03	2544.4	1.00E+09	620.23	7.85E+04
Total average 2000		497	3.48E+07	7.18E+07	77730	3.10E-03	2544.4	1.00E+09	1216.92	1.34E+05
Total average 2010		497	1.73E+08	4.10E+08	77730	2.70E-03	2544.4	1.00E+09	1059.64	1.34E+05

Tank truck ton miles - E100

Location	Btu/tmi	ton-mi	throughput	btu/Thput	hp-hr/MMBtu	btu/hp-h	k constant	hp-hr/kBtu	Gal Diesel
Truck/Chicago	712.4494	50.0000	3.93E-04	1.32E-05	5.00E-04	6.6720	1.00E+09	616.98	62973.2225
Truck/Peoria	676.8270	50.0000	3.93E-04	1.32E-05	5.00E-04	6.6720	1.00E+09	586.13	68596.4912
Truck/Lincoln	676.8270	50.0000	3.93E-04	1.32E-05	5.00E-04	6.6720	1.00E+09	586.13	68421.0526
Truck/Portland	676.8270	50.0000	3.93E-04	1.32E-05	5.00E-04	6.6720	1.00E+09	586.13	65175.4386
Truck/Tifton	676.8270	50.0000	3.93E-04	1.32E-05	5.00E-04	6.6720	1.00E+09	586.13	70964.9123
Truck/Rochester	676.8270	50.0000	3.93E-04	1.32E-05	5.00E-04	6.6720	1.00E+09	586.13	68596.4912
Total average 2000	712.4494	50.0000	3.93E-04	1.32E-05	5.00E-04	6.6720	1.00E+09	616.98	62973.2225
Total Average 2010	676.8270	50.0000	3.93E-04	1.32E-05	5.00E-04	6.6720	1.00E+09	586.13	68350.8772

*2000 Btu per ton mile = 128700 Btu/gal/(5.7MPG*9500gal/truck*6.7#/gal*(ton/2000) = 712.4494
*2010 Btu per ton mile = 128700 Btu/gal/(6MPG*9500gal/truck*6.7#/gal*(ton/2000) = 676.8270

Tank truck ton miles - E95 and E10

Location		Btu/tmi	ton-mi	throughput	btu/Thput	hp-hr/MMBtu	btu/hp-h	k constant	hp-hr/kBtu	Gal Diesel
Truck/Chicago	E10	759.9461	1.07E+08	3.93E-04	9.33E-06	5.00E-04	6.26	1.00E+09	435.93	629732.23
Truck/Peoria	E95	685.3944	1.36E+07	3.93E-04	1.29E-05	5.00E-04	6.59	1.00E+09	570.82	72192.98
Truck/Lincoln	E95	685.3944	1.35E+07	3.93E-04	1.29E-05	5.00E-04	6.59	1.00E+09	570.82	72035.09
Truck/Portland	E95	685.3944	1.29E+07	3.93E-04	1.29E-05	5.00E-04	6.59	1.00E+09	570.82	68596.49
Truck/Tifton	E95	685.3944	1.40E+07	3.93E-04	1.29E-05	5.00E-04	6.59	1.00E+09	570.82	74736.84
Truck/Rochester	E95	685.3944	1.36E+07	3.93E-04	1.29E-05	5.00E-04	6.59	1.00E+09	570.82	72219.30
Total average 2000		759.9461	1.07E+08	3.93E-04	9.33E-06	5.00E-04	6.26	1.00E+09	435.93	629732.23
Total Average 2010		685.3944	1.35E+07	3.93E-04	1.29E-05	5.00E-04	6.59	1.00E+09	570.82	71956.14

*2000 Btu per ton mile = 128700 Btu/gal/(5.7MPG*9500gal/truck*6.25#/gal*(ton/2000) = 759.9461
*2010 Btu per ton mile = 128700 Btu/gal/(6MPG*9500gal/truck*6.6#/gal*(ton/2000) = 685.3944

Ethanol System Efficiency Calculations - E100

Location	bhp\BBtu 100 % Rail	kwh/BBtu 100 % Bulk Storage	bhp\BBtu 100 % Trucks	kwh/BBtu 100 % retail Pumps	Includes Truck Backhaul Total gal Diesel #2	Into storage, Out of storage out of retail Station Total Kwh
Chicago	1265.37	2440.40	616.98	2440.40	192126.55	2.52E+07
Peoria	1405.33	2440.40	586.13	2440.40	233066.90	2.89E+07
Lincoln	1177.61	2440.40	586.13	2440.40	205888.69	2.88E+07
Portland	954.61	2440.40	586.13	2440.40	171324.88	2.75E+07
Tifton	1311.74	2440.40	586.13	2440.40	229782.09	2.99E+07
Rochester	644.87	2440.40	586.13	2440.40	144067.64	2.89E+07
Total average 2000	1265.37	2440.40	616.98	2440.40	192126.55	2.52E+07
Total Average 2010	1101.71	2440.40	586.13	2440.40	196826.04	2.88E+07

Ethanol System Efficiency Calculations - E95 and E10

Location	bhp\BBtu 100 % Rail	kwh/BBtu 100 % Bulk Storage	bhp\BBtu 100 % Trucks	kwh/BBtu 100 % retail Pumps	Incls Truck Backhaul Total gal Diesel #2	Into storage, Out of storage out of retail Station Total Kwh
Chicago	1216.92	2440.40	435.93	2440.40	764003.39	1.97E+08
Peoria	1352.01	2440.40	570.82	2440.40	243185.16	3.12E+07
Lincoln	1132.52	2440.40	570.82	2440.40	214954.72	3.12E+07
Portland	918.42	2440.40	570.82	2440.40	178964.68	2.97E+07
Tifton	1261.21	2440.40	570.82	2440.40	239865.97	3.23E+07
Rochester	620.23	2440.40	570.82	2440.40	150689.93	3.12E+07
Total average 2000	1216.9222	2440.40	435.9263	2440.40	764003.39	1.97E+08
Total Average 2010	1059.6442	2440.40	570.8206	2440.40	205532.09	3.11E+07

BSFC	2000	0.46
	2010	0.44

Pollutant Calculations grams per thou Btu of throughput - E100

	HC		CO		NOx	
	Rail	Truck	Rail	Truck	Rail	Truck
Chicago	0.00019	0.000188	0.00072	0.000563	0.00335	0.000713
Peoria	0.00016	0.000093	0.00053	0.000373	0.00266	0.000373
Lincoln	0.00013	0.000093	0.00045	0.000373	0.00223	0.000373
Portland	0.00011	0.000093	0.00036	0.000373	0.00181	0.000373
Tifton	0.00015	0.000093	0.00050	0.000373	0.00248	0.000373
Rochester	0.00007	0.000093	0.00024	0.000373	0.00122	0.000373
Total average 2000	0.00019	0.000188	0.00072	0.000563	0.00335	0.000713
Total Average 2010	0.00013	0.000093	0.00042	0.000373	0.00208	0.000373

	PM		CO2		SOx	
	Rail	Truck	Rail	Truck	Rail	Truck
Chicago	0.000072	0.000015	0.2573	0.1254	0.000080	0.000039
Peoria	0.000053	0.000015	0.2857	0.1192	0.000089	0.000037
Lincoln	0.000045	0.000015	0.2394	0.1192	0.000075	0.000037
Portland	0.000036	0.000015	0.1941	0.1192	0.000061	0.000037
Tifton	0.000050	0.000015	0.2667	0.1192	0.000083	0.000037
Rochester	0.000024	0.000015	0.1311	0.1192	0.000041	0.000037
Total average 2000	0.000072	0.000015	0.2573	0.1254	0.000080	0.000039
Total Average 2010	0.000042	0.000015	0.2240	0.1192	0.000070	0.000037

Pollutant Calculations grams per thou Btu of throughput - E95 and E10

	HC		CO		NOx	
	Rail	Truck	Rail	Truck	Rail	Truck
Chicago	0.00018	0.000133	0.00069	0.000398	0.00322	0.000504
Peoria	0.00015	0.000091	0.00051	0.000363	0.00256	0.000363
Lincoln	0.00013	0.000091	0.00043	0.000363	0.00214	0.000363
Portland	0.00010	0.000091	0.00035	0.000363	0.00174	0.000363
Tifton	0.00014	0.000091	0.00048	0.000363	0.00239	0.000363
Rochester	0.00007	0.000091	0.00023	0.000363	0.00117	0.000363
Total average 2000	0.00018	0.000133	0.00069	0.000398	0.00322	0.000504
Total Average 2010	0.00012	0.000091	0.00040	0.000363	0.00200	0.000363

	PM		CO2		SOx	
	Rail	Truck	Rail	Truck	Rail	Truck
Chicago	0.000069	0.000011	0.2474	0.0886	0.000077	0.000028
Peoria	0.000051	0.000015	0.2749	0.1161	0.000086	0.000036
Lincoln	0.000043	0.000015	0.2303	0.1161	0.000072	0.000036
Portland	0.000035	0.000015	0.1867	0.1161	0.000058	0.000036
Tifton	0.000048	0.000015	0.2564	0.1161	0.000080	0.000036
Rochester	0.000023	0.000015	0.1261	0.1161	0.000039	0.000036
Total average 2000	0.000069	0.000011	0.2474	0.0886	0.000077	0.000028
Total Average 2010	0.000040	0.000015	0.2154	0.1161	0.000067	0.000036

E100 Pounds of emissions per MMBtu of throughput

	Fully Corrected 2000	Fully Corrected 2010
HC	0.000835	0.000481
CO	0.002822	0.001739
NOx	0.008952	0.005411
PM	0.000191	0.000125
CO2	0.842989	0.755880
SOx	0.000263	0.000236

E100 Tons of emissions for total throughput No back haul

	Fully Corrected 2000	Fully Corrected 2010
HC	2.1562	7.0894
CO	7.2850	25.6500
NOx	23.1087	79.7996
PM	0.4937	1.8382
CO2	2176.0674	11146.4742
SOx	0.6800	3.4833

E100 pounds of emissions per MMBtu of throughput

	Chicago	Peoria	Lincoln	Portland	Tifton	Rochester
HC	0.000835	0.000557	0.000500	0.000444	0.000533	0.000367
CO	0.002822	0.001992	0.001803	0.001617	0.001914	0.001359
NOx	0.008952	0.006676	0.005728	0.004799	0.006287	0.003508
PM	0.000191	0.000150	0.000131	0.000112	0.000142	0.000087
CO2	0.842989	0.891852	0.789872	0.690003	0.849937	0.551288
SO2	0.000263	0.000279	0.000247	0.000216	0.000266	0.000172

E100 Tons of emissions for total throughput No back haul

	Chicago	Peoria	Lincoln	Portland	Tifton	Rochester
HC	2.1562	1.6476	1.4753	1.2486	1.6329	1.0850
CO	7.2850	5.8973	5.3220	4.5470	5.8621	4.0217
NOx	23.1087	19.7614	16.9099	13.4949	19.2497	10.3836
PM	0.4937	0.4439	0.3867	0.3161	0.4353	0.2563
CO2	2176.0674	2639.7668	2331.9404	1940.4631	2602.5623	1631.7416
SO2	0.6800	0.8249	0.7287	0.6064	0.8133	0.5099

E95 and E10 Pounds of Emission per MMBtu of throughput

	Fully Corrected 2000	Fully Corrected 2010
HC	0.000698	0.00046488
CO	0.002398	0.00168291
NOx	0.008208	0.00521476
PM	0.000175	0.00012029
CO2	0.740210	0.73018553
SOx	0.000231	0.00022818

E95 and E10 Tons of Emission for total throughput No back haul

	Fully Corrected 2000	Fully Corrected 2010
HC	25.4932	8.7076
CO	87.5936	31.5226
NOx	299.8909	97.6777
PM	6.4110	2.2532
CO2	27043.3733	13677.0955
SOx	8.4511	4.2741

E95 and E10 Pounds of emissions per MMBtu of throughput

	Chicago	Peoria	Lincoln	Portland	Tifton	Rochester
HC	0.000698	0.000538	0.000483	0.000430	0.000515	0.000355
CO	0.002398	0.001927	0.001744	0.001565	0.001851	0.001317
NOx	0.008208	0.006433	0.005518	0.004626	0.006055	0.003384
PM	0.000175	0.000145	0.000126	0.000109	0.000137	0.000084
CO2	0.740210	0.861120	0.762824	0.666940	0.820456	0.533399
SO2	0.000231	0.000269	0.000238	0.000208	0.000256	0.000167

E95 and E10 Tons of emissions for total throughput No back haul

	Chicago	Peoria	Lincoln	Portland	Tifton	Rochester
HC	25.4932	1.7207	1.5418	1.3056	1.7062	1.1360
CO	87.5936	6.1622	5.5650	4.7571	6.1288	4.2133
NOx	299.8909	20.5761	17.6125	14.0607	20.0485	10.8281
PM	6.4110	0.4627	0.4033	0.3298	0.4539	0.2678
CO2	27043.3733	2754.3684	2434.6243	2026.9932	2716.7746	1706.7472
SO2	8.4511	0.8607	0.7608	0.6334	0.8490	0.5334

Spill data: Total gallons for each fuel cycle

	Chicago	Peoria	Lincoln	Portland	Tifton	Rochester
Rail	781.3420	895.6051	893.6463	850.9880	927.1634	895.9315
Bulk plant	1812.1231	158.6500	158.3031	150.7465	164.2404	158.7079
Truck	13883.2012	1215.4640	1212.8056	1154.9123	1258.2932	1215.9071
Refueling	6.0000	0.5253	0.5241	0.4991	0.5438	0.5255
Total	16482.6663	2270.2444	2265.2791	2157.1460	2350.2409	2271.0720

**used the gal/Bil btu numbers times billions of btu's of fuel.

VOC Emissions from Ethanol Distribution Worksheet

Values Table		100 F RVP	55 F PSI	S	#/#-mole Mv	T	Atmospheric Pressure	Kc
E100		2.3	0.5	0.6	46	515	14.7	1
E10		10	4.7	0.6	64.6	515	14.7	1
E95	3.3	2.6	0.69	0.6	47	515	14.7	
Reformulated		9	4.2	0.6	66.7	515	14.7	
Conventional		10	4.7					

	Diameter	Height	Tempchang	reflective index Fp	C	Volume	Turnovers/yr N	Turnover Factor Kn
E100	10.5	11.5	20	1	0.5	15000	Cal'd below	1
E10	10.5	11.5	20	1	0.5	15000	Cal'd below	1
E95	10.5	11.5	20	1	0.5	15000	Cal'd below	1
Reformulated	10.5	11.5	20	1	0.5	15000	5.7	1
Conventional								

TRANSIT LOSS EMISSION FACTOR:

L1 = (0.0 +0.01)/2 = .005 #/1000 gallons for Convention Gasoline RVP 10

If transit losses in #/1000 gal are proportional wrt RVP then:

.005 * ratio of 55F PSI of gasoline to PSI of fuel

Assume that E10 has same transit loss factor as RVP 9 gasoline

E10:
(PSI G9 / PSI G10) * .005 #/1000 gal throughput = 0.004468085

E95:
PSI E95 / PSI G10 * .005 #/1000 gal throughput = 0.000734042

Reformulated RVP 9 0.004468085

TRANSIT LOSS EMISSION FACTOR:

	Rail Volume	Truck Volume	VOC pounds Transit losses Rail	VOC pounds Transit losses Truck	Tons Total Transit Losses
Chicago	7.18E+07	6.82E+08	5.27E+01	3.05E+03	1.549969148
Peoria	8.23E+07	8.23E+07	6.04E+01	6.04E+01	0.060411702
Lincoln	8.21E+07	8.21E+07	6.03E+01	6.03E+01	0.060279574
Portland	7.82E+07	7.82E+07	5.74E+01	5.74E+01	0.057402127
Tifton	8.52E+07	8.52E+07	6.25E+01	6.25E+01	0.062540425
Rochester	8.23E+07	8.23E+07	6.04E+01	6.04E+01	0.060433723

LOADING LOSS EMISSION FACTOR L2:

L2* = (12.46 * (S*P*M)/T)= uncontrolled tanker loading loss

L2 * (1-.67)*(1-.95 or 98) = controlled tanker loading losses

Loading Loss Factor E10:

L2*	=	4.41	
L2	=	0.07	2000
L2	=	0.03	2010

Loading Loss Factor E95

L2*	=	0.47	
L2	=	0.01	2000
L2	=	0.00	2010

LOADING LOSS EMISSION FACTOR L2:

	Rail Volume	Truck Volume	VOC pounds Loading Losses Rail	VOC pounds Truck	Tons Total loading Losses
Chicago	7.18E+07	6.82E+08	5.58E+02	4.96E+04	49.91650107
Peoria	8.23E+07	8.23E+07	2.56E+02	2.56E+02	0.383877319
Lincoln	8.21E+07	8.21E+07	2.55E+02	2.55E+02	0.383037733
Portland	7.82E+07	7.82E+07	2.43E+02	2.43E+02	0.364753418
Tifton	8.52E+07	8.52E+07	2.65E+02	2.65E+02	0.397403980
Rochester	8.23E+07	8.23E+07	2.56E+02	2.56E+02	0.384017250

Note: Assumes you load train, unload train, load trucks, unload trucks.
In the unloading of the train, the displaced emissions in the storage tank are accounted for in tank working loss estimates.
In unloading trucks, equal vapors in retail storage are offset, same as in truck.
Thus, train emissions + (2 * truck emissions)

FACILITY AND STORAGE TANK EMISSIONS

Breathing losses #/yr:

Lb = 2.26/100*Mv*((P/Pa-P)^.68)*(D^1.73)*(Hv^.51)*(xT^.5)*(FpCKc) =

Working losses #/yr:

Lw = (2.4x10^-5)*(Mv*PVNKnKc) =

(Lb + Lw)*(1-.95) = Lt

Assume that bulk plants used for ethanol are specially altered and are dedicated to ethanol throughput (max turnovers: 133 per year per plant) All bulk plants contain E95. E10 blends are created when trucks are loaded. Plant size = 1700000 gal per year. Plant efficiency 90%. Breathing losses are per plant per year.

Note: for the Regional areas, each major city has one or more bulk plants that are dedicated to ethanol and thus, efficiently utilize its capacity by maximizing the throughput of the facility to the extent possible.

Chicago	#/yr Per plant	No. of Bulkplants	No. of turnovers
Lb =	61.93	46.93	102.00
Lw =	1182.20		
Lt =	62.21		

Total Breathing losses tons = 1.459615345

Tot. Breathing loss pounds/Bil Btu of throughput = 0.523064570

FACILITY AND STORAGE TANK EMISSIONS

Peoria	#/yr Per plant	No. of Bulkplants	No. of turnovers
Lb =	61.93	53.79	102.00
Lw =	1182.20		
Lt =	62.21		

Total Breathing losses tons = 1.673068843
Tot. Breathing loss pounds/Bil Btu of throughput = 0.599557300

Lincoln	#/yr Per plant	No. of Bulkplants	No. of turnovers
Lb =	61.93	53.67	102.00
Lw =	1182.20	0.00	
Lt =	62.21		

Total Breathing losses tons = 1.669409640
Tot. Breathing loss pounds/Bil Btu of throughput = 0.598245996

Portland	#/yr Per plant	No. of Bulkplants	No. of turnovers
Lb =	61.93	51.11	102.00
Lw =	1182.20		
Lt =	62.21		

Total Breathing losses tons = 1.589720334
Tot. Breathing loss pounds/Bil Btu of throughput = 0.569688710

FACILITY AND STORAGE TANK EMISSIONS

Tifton	#/yr Per plant	No. of Bulkplants	No. of turnovers
Lb =	61.93	55.69	102.00
Lw =	1182.20		
Lt =	62.21		

Total Breathing losses tons = 1.732022666

Tot. Breathing loss pounds/Bil Btu of throughput = 0.620683863

Rochester	#/yr Per plant	No. of Bulkplants	No. of turnovers
Lb =	61.93	53.81	102.00
Lw =	1182.20		
Lt =	62.21		

Total Breathing losses tons = 1.673678710

Tot. Breathing loss pounds/Bil Btu of throughput = 0.599775850

UNDERGROUND BREATHING LOSSES FOR RETAIL STATIONS

Breathing loss factor RVP 10 = 1 #/1000 gal throughput
Breathing loss factor RVP 9 = (9/10) * 1 #/1000 gal = .9 #/1000 gal
Breathing loss factor for RVP 6.7 = .67 #/1000 gal

RVP E10 = RVP 9 gasoline. .9 # VOC/1000 gal throughput
E95 = 2.6/10 * 1 = .26 #/1000 gal

Total tons of VOC from retail storage:

Chicago	306.90
Peoria	10.70
Lincoln	10.68
Portland	10.17
Tifton	11.08
Rochester	10.70

VOC EMISSIONS FROM VEHICLE REFUELING

Vapor loss (g/gal) = -5.909 - .094(Tf-Td) + .084(Td) + .485 (RVP)
95 % vapor control efficiency

Tf = 52 F
Td = 55 F

		Working calculations	
E10 Vapor Loss g/gal:	0.1679	3.358	4.365
E95 Vapor Loss g/gal:	0.0127	0.254	1.261

Total tons of VOC from refueling:

Chicago	126.11
Peoria	1.15
Lincoln	1.15
Portland	1.09
Tifton	1.23
Rochester	1.15

Total Tons of VOC Emissions from NON-vehicle sources

Chicago	485.9359974
Peoria	13.96747019
Lincoln	13.93692166
Portland	13.27164240
Tifton	14.50160143
Rochester	13.97256162

APPENDIX D

ETHANOL FUEL TRANSPORTATION AND DISTRIBUTION

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APPENDIX D

ETHANOL FUEL TRANSPORTATION AND DISTRIBUTION

D.1 Introduction and Background

In this section, an overview of the ethanol distribution system portion of the ethanol fuel cycle study is provided. Included are discussions of the study objectives, the general methodology, the report structure, and the general study assumptions.

D.1.1 Introduction

The U.S. Department of Energy, through the National Renewable Energy Laboratory, has embarked upon a program to develop technologies for the production of fuel-grade ethanol from renewable biomass resources. The lignocellulosic biomass-to-ethanol program will invest in the development of the process and will work closely with industry to move the new technology from the laboratory to the market place.

Given the complexity of interactions among energy sources, the environment, and society, it is becoming increasingly apparent that the choice of energy technologies must be based on a comprehensive analysis. One means of comprehensively assessing an emerging technology like biomass-to-ethanol is to characterize and evaluate it using a fuel cycle analysis. The assessment can include technical, economic, environmental, or other evaluation factors. In addition, the technology must be compared to a benchmark energy technology that can be either existing technologies or other alternatives. In other words, the role of the total fuel cycle analysis is to assess the merits of competing fuel technologies in similar end uses.

For this overall effort, the benchmark fuel which has been chosen is reformulated gasoline. The reformulated gasoline fuel cycle analysis is being characterized in accompanying work to this study. This study characterizes the distribution system infrastructure portion of the overall biomass-to-ethanol fuel cycle analysis. The other components of the ethanol fuel cycle analysis include Biomass Production, Storage, Transportation, MSW Collection, Transportation, Separation, Biomass Conversion, and Ethanol End-Use.

The overall biomass-to-ethanol and reformulated gasoline fuel cycle analyses are the first phase of an ongoing effort by the U.S. Department of Energy to characterize and compare transportation fuel alternatives.

D.1.2 Study Objective

The major objective of this study is to assess the environmental impacts of transporting and distributing ethanol from the production plant up to final vehicle end-use. It is important to remember that the results of this study are based on necessary assumptions and readily available data.

D.1.3 Study Methodology and Approach

The study methodology consisted of three main steps:

1) characterize the ethanol consumption sectors for each assumed plant site

2) characterize the ethanol distribution system for each assumed site

3) assess the environmental impacts of ethanol transportation and distribution

The ethanol distribution fuel cycle analysis was conducted for two different time frames: 2000 and 2010. The technologies selected for the analysis were consistent with the time periods of evaluation. Current data were used where appropriate, and assumptions used to translate these data into estimates relevant to years 2000 and 2010.

The concentration of effort in defining environmental impacts for the ethanol distribution infrastructure was placed on the operational phase. While major activities of the pre-operational and post-operational phases were qualitatively described, only the operating phase was quantitatively characterized with respect to inputs, outputs, processes, environmental emissions. Additionally, only primary inputs and outputs were considered for this study.

D.2 Assumptions

In quantifying the emission factors for the transportation and storage of ethanol, several important assumptions were required. The assumptions of this section are divided into general assumptions, and those for ethanol transport, bulk plant transferral and storage, retail outlet transferral and storage, and commercial/rural transfer and storage assumptions. The assumptions are listed for the years 2000 and 2010 when different.

D.2.1 General Assumptions

<u>Years 2000 and 2010</u>

- o RVP of neat ethanol = 2.3 psi (Obert 1973)

- o RVP of gasoline = 9 psi (U.S. Congress 1990)

- o Lower heating value of neat ethanol = 75,670 Btu/gal

- o Lower heating value of gasoline = 115,400 Btu/gal

- o In the year 2000 there is only one ethanol plant located in Peoria, Illinois. In 2000, the plant produces 68.2 million gallons of ethanol and adds to it 3.6 million gallons of the reformulated gasoline producing E95 product (95 percent by volume (vol%) ethanol and 5 vol% reformulated gasoline). The reformulated gasoline does not contain an oxygenate portion and its RVP is 9.0 psi. The E95 product is transported to bulk plants in Chicago (the single ethanol consumption site in 2000) by rail tank car where it is further blended with reformulated gasoline for distribution as E10 (10 vol% ethanol, 90 vol% gasoline). Tank trucks distribute the E10 to service stations and fleet fueling facilities.

- o In the year 2010 there are a total of 5 ethanol plants located throughout the country producing between 74 and 81 million gallons of ethanol per year. The ethanol plants are located in Peoria, Illinois; Tifton, Georgia; Rochester, New York; Portland, Oregon; and Lincoln, Nebraska. The ethanol is blended with enough reformulated gasoline in each of these plants to produce E95 product. The reformulated gasoline does not contain an oxygenate portion and its RVP is 9.0 psi. Rail transport is assumed to deliver the E95 to the bulk plants located within the major consumption areas of each site. From the bulk plants, the E95 is distributed to service station and commercial fleet fueling facilities via tank truck.

- o Transportation of E95 and E10 at ambient temperatures of 55 ^{o}F
  - assumed average national temperature representing the typical ozone nonattainment period

- o Fuel spills along the ethanol transportation infrastructure are quantified based on accidental fuel spill rate data for crude oil and refined products gasoline (USCG 1986). Small spills associated with normal operational procedures (such as those associated with hose disconnect) for most of the ethanol distribution infrastructure will not be quantified. Ethanol spills at service stations were estimated based on calculated gasoline spill data at service stations for normal end-use vehicle refueling operations (EA Mueller 1989).

D.2.2 Ethanol Transport

<u>Years 2000 and 2010</u>

In both scenarios, ethanol product was assumed to be transported by rail tank car and tank truck throughout the entire transportation infrastructure assumed for this analysis.

- o Lower heating value of No. 2 diesel fuel = 128,700 Btu/gal (ORNL 1991)

- o Rail/Tank Truck

- Assume rail cars have the same vapor leakage rates as tank trucks based on a similar assumption by EPA in its emission factor document, AP-42 (EPA 1985 a) and since tank hatch designs between these two transportation modes are similar.
- Use of vapor tight rail cars and tank trucks which must meet annual certification based on future NSPS requirements for VOC control from petroleum product transferral at bulk terminals and bulk plants (EPA 1988 a). Assume a 67 percent reduction in vapor emissions during loading practices which such rail cars and tank trucks based on EPA estimates in proposed benzene regulations for the gasoline industry (EPA 1989).
- Submerged loading practices only based on characterization of current gasoline marketing practices (EPA 1985 a, EPA 1989, Arthur D. Little 1979), and future NSPS requirements for VOC control from petroleum product transferral at bulk terminals and bulk plants (EPA 1988 a).
- Locomotive engine bsfc of 0.37 lb/bhp-hr based on data from typical locomotive medium speed diesel engines (Wakenell 1985). The 1990 values will be used for 2000 and 2010 assuming that new locomotive turnover is very slow.
- Tank truck fuel economy of 5.3 MPG assumed for 1990 based on average national value for tractor/trailer combinations (MVMA 1990) since this value generally represents Class 7 and Class 8 diesel trucks such as used on tank trucks. This value was projected to 5.7 MPG in 2000 and 6.0 MPG in 2010 based on NES (DOE 1991) fuel economy projections for highway vehicles carrying freight. These values will be placed on a brake specific basis using bhp-hr/mile conversion data for future Class 8 trucks (MVMA 1983). An average haul length of 50 miles was assumed for tank trucks in the ethanol distribution system.

o Spills
  - Spills occurring during the transport of ethanol by rail and tank trucks are based on U.S. Coast Guard petroleum spill data (USCG 1986). The spill rate (gallon/year) was based on a four year average (1983 to 1986) of spills as recorded by the Coast Guard. The spill rates for ethanol in 2000 and 2010 were determined for each mode of ethanol transportation based on NES values given for total petroleum liquids transported in years 2000 and 2010.

D.2.3 Bulk Plant Ethanol Transferral and Storage

<u>Years 2000 and 2010</u>

o Bulk plants receive E95 from the ethanol plants by rail tank cars. In 2000, the E95 is blended to E10 with reformulated gasoline. In 2010, the E95 is distributed as received.

o Bulk plants that will store ethanol product use vapor balance systems (Stage 1 controls) for product transferral and storage at average efficiencies of 95 percent based on EPA estimates in future regulations for benzene control at bulk product terminal facilities (EPA 1989).

- Bulk plants are assumed to have a single 15,000 gallon capacity fixed roof ethanol storage tank in addition to the typical gasoline storage tanks currently used by bulk plants (EPA 1989, EIA 1991 a). This tank size was selected based on existing typical fixed roof storage tanks used in bulk plants.

- Each bulk plant which is capable of storing ethanol product in the year 2000 is expected to have a throughput of approximately 28,300 gal/year (5 percent of the gasoline throughput at a current bulk plant near Chicago). The 5 percent value was determined based on the estimated current gasoline consumption by the population in the Chicago area.

- In the year 2010, there are five ethanol plants supplying the bulk plants within five major consumption areas. The ethanol throughput for bulk plants is assumed to be nine percent of the existing gasoline throughput from the five major consumption areas. The corresponding estimated ethanol throughput in 2010 for a typical bulk plant is assumed to be 51,000 gallons per year.

D.2.4 Commercial/Rural Fuel Facilities

Years 2000 and 2010

- The commercial and rural fuel facilities receive ethanol product from tank trucks.

- These facilities are assumed to use underground storage tanks of 4,000 gallons each. Assumption based on project team experience with gasoline fleet vehicle operations and refueling facilities. Such tanks will also have to be constructed to meet EPA leak containment regulations (EPA 1988 b).

- This type of facility is assumed to use Stage 2 vapor recovery systems with typical efficiencies of 95 percent. This efficiency is based on EPA estimates for refueling gasoline vehicles (EPA 1989, U.S. Congress 1990, Multinational Business Services 987).

- Vehicle refueling vapor emissions are based on an EPA estimated and experimentally derived refueling vapor generation equation and is adjusted to the physical properties of ethanol product (E95 or E10).

- The ethanol refueling spill rate is based on actual in use data collected for gasoline (EA Mueller 1989).

- o Ethanol storage tank vapor losses attributed to "breathing" were based on average breathing losses as reported in AP-42, and adjusted to the physical properties of ethanol product (E95 or E10) (EPA 1985 a).

- o Commercial and rural accounts use Stage 2 vapor recovery systems with typical efficiencies of 95 percent when refueling vehicles. This efficiency is based on EPA estimates for gasoline vapor recovery efficiency (U.S. Congress 1990, EPA 1989, Multinational Business Services 1987).

D.2.5 Retail Outlets

<u>Years 2000 and 2010</u>

- o Retail outlets receive ethanol product from tank trucks.

- o The outlets use vapor balance systems (Stage 1 controls) for product transferral from tank trucks to storage at average efficiencies of 95 percent based on EPA estimates in future regulations for VOC control at bulk product gasoline terminal facilities (EPA 1989).

- o Use of underground storage tanks of 10,000 gallons each based on characterization given in proposed future benzene control regulations for gasoline retail outlets (EPA 1989). Such tanks will be constructed to meet EPA leak containment regulations (EPA 1988 b).

- o Retail outlets use Stage 2 vapor recovery systems with typical efficiencies of 95 percent when refueling vehicles based on EPA estimates for gasoline vehicle refueling (U.S. Congress 1990, EPA 1989, Multinational Business Services 1987).

- o Vehicle refueling vapor emissions are based on an EPA estimated and experimentally derived refueling vapor generation equation based on gasoline and adjusted for the physical properties of ethanol product (E95 or E10).

- o Ethanol refueling spill rate based on actual in use data collected for gasoline (EA Mueller 1989).

o Storage tank ethanol vapor losses attributed to "breathing" were based on average breathing losses for gasoline as reported in AP-42, and adjusted for the physical properties of ethanol product (E95 or E10) (EPA 1985 a).

- o Retail service stations use vapor balance systems (Stage 1 controls) for product transferral from tank trucks to storage at average efficiencies of 95 percent based on EPA estimates in future regulations for VOC control at bulk product terminals facilities (EPA 1989).

- o Typical service stations use underground storage tanks of 10,000 gallons each based on characterization given in proposed future benzene control regulations for gasoline (EPA 1989). Such tanks will be constructed to meet EPA leak containment regulations (EPA 1988 b).

- o Service stations use Stage 2 vapor recovery systems with typical efficiencies of 95 percent when refueling vehicles based on EPA estimates (U.S. Congress 1990, EPA 1989, Multinational Business Services 1987).

D.3 Ethanol Distribution Infrastructure for this Study

The ethanol distribution infrastructure assumed for this report was essentially based on the current gasoline secondary distribution and tertiary storage system. A basic assumption for this analysis was that the same types of gasoline transport modes and gasoline storage facilities could also be used in an ethanol distribution system. This assumption was made due the relatively low volumes of ethanol production in this study.

For this study, five potential ethanol production sites were assumed. These sites included Peoria, Illinois, Lincoln, Nebraska, Tifton, Georgia, Rochester, New York, and Portland, Oregon. In year 2000, it was assumed that only the Peoria plant would be operational and producing 68.2 million gallons of ethanol fuel. This ethanol was assumed to be added to reformulated gasoline to produce E95. All of this E95 output was then assumed to be further blended with reformulated gasoline at bulk plants to produce E10. The E10 was all assumed to be consumed in Chicago.

In year 2010, however, all five sites were assumed to be operational and producing between 74 and 81 million gallons of ethanol for consumption in a number of regional locations. The ethanol was assumed to be blended to E95 with reformulated gasoline at each of the five plants. The E95 product was then assumed to be distributed by rail car and tank truck to ultimate consumption in a number of regional consumption sectors.

An analysis was performed to determine these regional consumption sectors for each of the five ethanol production sites. First, it was assumed that a reasonable area of distribution for the ethanol plants would be a 200 mile radius. In addition, it was assumed that only those urban area populations of 50,000 or more would make economically feasible ethanol consumption sectors when accounting for transportation costs. An exception to this assumption was the production plant themselves, which were assumed to consume portions of their ethanol production even though their populations may not exceed 50,000.

Based on these assumptions, a number of potential ethanol consumption sectors in the regions of each of the five ethanol production sites were determined. The amount of ethanol consumption in each of the urban consumption sectors of the five sites was assumed to be proportional to the population of those consumption sectors. In this way, the ethanol production for each site was apportioned among the consumption areas associated with it.

Tables D-1 through D-5 list the ethanol consumption sector characteristics for each of the five ethanol production sites in 2010. Average distances from the production site to each of its consumption sectors were derived by measuring straight line map distances (Rand-McNally 1986).

The ethanol distribution infrastructure assumed for this report was based on the current gasoline secondary distribution and tertiary storage system. A basic assumption for this analysis was that the same types of gasoline transport modes and gasoline storage facilities could also be used in an ethanol distribution system.

Since the ethanol production levels from the plants of this study are relatively modest, and the distribution of the ethanol would be isolated to relatively regional (200 miles) areas, the use of bulk product terminals as used in the current gasoline distribution system were not assumed for ethanol distribution. Instead, the ethanol product (E95 and E10) was assumed to be transported from each production site directly to bulk plants in each of its consumption sectors. From the bulk plants, the ethanol product would then be distributed to commercial accounts and service stations.

An assessment was made to determine the most feasible transport modes for transporting the ethanol from the production plants to the bulk plants in each consumption sector. Based on regional maps of freight rail lines, it was determined that all potential ethanol consumption sectors could be serviced with rail cars, as shown in Tables D-1 through D-5. Although product pipelines exist in some ethanol production site regions, the use of railroad were assumed to make better economical sense given the low levels of ethanol production. The use of current crude or gasoline railroad tankers would require less physical modifications to make them compatible with ethanol, and the rail cars could be used as short-term intermediate storage.

The overall local ethanol distribution infrastructure assumed for this study is represented by Figure D-1.

D.4 Process Environmental Points of Interest

In this section, the environmental impacts of ethanol product distribution are addressed. The section includes a discussion of the major inputs and outputs of the ethanol product distribution infrastructure. In addition, the major environmental effects of the ethanol product distribution infrastructure are presented and quantified.

Table D-1.
Ethanol Plant Consumption Sector Characterization for Peoria, Illinois for Year 2010

Consumption Site	Percent of Total Annual Ethanol Consumption	Total Annual Ethanol Consumption (Million Gal/Yr)	Distance from Production Plant (Miles)	Mode of Ethanol Transportation to Site
Peoria, Illinois	2.2	1.7	0	----
Chicago, Illinois	54.2	42.4	157	Rail
Milwaukee, Wisconsin	11.5	9.0	210	Rail
Madison, Wisconsin	3.1	2.4	205	Rail
Rockford, Illinois	2.5	1.9	120	Rail
Cedar Rapids, Iowa	2.0	1.6	140	Rail
Davenport, Iowa	1.9	1.5	96	Rail
Springfield, Illinois	1.8	1.4	73	Rail
St. Louis, Missouri	8.2	6.4	148	Rail
Indianapolis, Indiana	12.6	9.9	211	Rail

Table D-2.
Ethanol Plant Consumption Sector Characterization for Lincoln, Nebraska for Year 2010

Consumption Site	Percent of Total Annual Ethanol Consumption	Total Annual Ethanol Consumption (Million Gal/Yr)	Distance from Production Plant (Miles)	Mode of Ethanol Transportation to Site
Lincoln, Nebraska	2.6	2.0	0	----
Omaha, Nebraska	21.9	17.1	56	Rail
Des Moines, Iowa	13.4	10.5	172	Rail
Souix City, Iowa	5.8	4.5	125	Rail
Kansas City, Kansas	11.3	8.8	170	Rail
Kansas City, Missouri	31.5	24.6	177	Rail
Topeka, Kansas	8.1	6.3	142	Rail
St. Joseph, Missouri	5.4	4.2	144	Rail

Table D-3.
Ethanol Plant Consumption Sector Characterization for Tifton, Georgia for Year 2010

Consumption Site	Percent of Total Annual Ethanol Consumption	Total Annual Ethanol Consumption (Million Gal/Yr)	Distance from Production Plant (Miles)	Mode of Ethanol Transportation to Site
Tifton, Georgia	0.8	0.6	0	----
Atlanta, Georgia	25.5	20.6	182	Rail
Macon, Georgia	7.0	5.7	100	Rail
Columbus, Georgia	10.2	8.3	117	Rail
Montgomery, Alabama	10.7	8.7	200	Rail
Savannah, Georgia	8.5	6.9	153	Rail
Jacksonville, Florida	32.4	26.2	149	Rail
Tallahassee, Florida	4.9	3.9	89	Rail

Table D-4.
Ethanol Plant Consumption Sector Characterization for Rochester, New York for Year 2010

Consumption Site	Percent of Total Annual Ethanol Consumption	Total Annual Ethanol Consumption (Million Gal/Yr)	Distance from Production Plant (Miles)	Mode of Ethanol Transportation to Site
Rochester, New York	23.1	18.1	0	----
Buffalo, New York	34.1	26.7	69	Rail
Niagara Falls, New York	6.8	5.3	74	Rail
Syracuse, New York	16.2	12.7	77	Rail
Erie, Pennsylvania	11.4	8.9	150	Rail
Scranton, Pennsylvania	8.4	6.5	170	Rail

Table D-5.
Ethanol Plant Consumption Sector Characterization for Portland, Oregon for Year 2010

Consumption Site	Percent of Total Annual Ethanol Consumption	Total Annual Ethanol Consumption (Million Gal/Yr)	Distance from Production Plant (Miles)	Mode of Ethanol Transportation to Site
Portland, Oregon	31.5	23.4	0	----
Salem, Oregon	7.7	5.7	42	Rail
Tacoma, Washington	13.6	10.1	123	Rail
Seattle, Washington	42.5	31.6	172	Rail
Everett, Washington	4.7	3.5	187	Rail

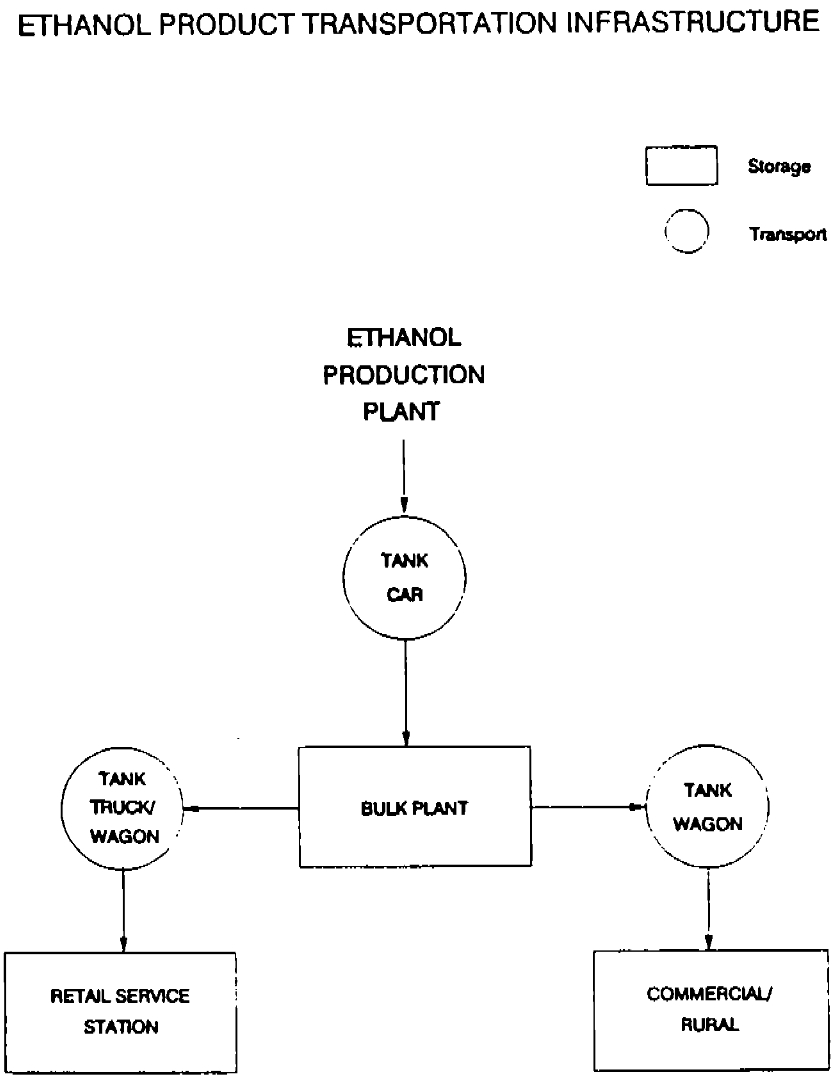

Figure D-1. Ethanol Distribution System Assumed for this Study

D.4.1 Inputs and Outputs to Ethanol Transport Operations

An assessment of the inputs and outputs of the ethanol fuel transportation process was made. The inputs relate to the requirements for moving the ethanol to the end-use sector, while outputs relate to the actual products or outputs from this process. Table D-6 summarizes the major inputs and outputs to the ethanol product transportation infrastructure.

Table D-6.
Input and Output Estimates of Ethanol Transportation Infrastructure

Inputs			Outputs		
Substance	Quantity		Substance	Quantity	
	2000	2010		2000	2010
Ethanol	68.2 million gal/year	390 million gal/year	Ethanol[1]	68.2 million gal/year	390 million gal/year
No. 2 Diesel Fuel	12.3 BBL/D	60.5 BBL/D			
Electricity	69,000 kw-hr/D	395,000 kw-hr/D			
Replacement Parts	N/A[2]	N/A			
Labor	496	2830			

[1] Ethanol output assumes negligible product VOC and liquid spill losses over the transportation infrastructure based on the emission factors calculated below.
[2] N/A - not available

No. 2 diesel was assumed to be used by locomotives moving rail cars and tank trucks. Pumps at bulk plants and service stations were assumed to be driven exclusively by electric motors.

The ethanol inputs and outputs were derived from the ethanol production assumptions for 2000 and 2010 (DOE 1991). The input estimates for No. 2 diesel fuel were derived from the ethanol production levels and weighted average transport efficiencies for those modes using this fuel in the infrastructure. The electricity input was estimated by accounting for and weighting the transportation efficiencies for using electricity for bulk facility pumps along the ethanol distribution infrastructure. Labor requirements were derived from 1987 employment figures for the gasoline wholesale and retail industry (API 1990), total gasoline supplied to end users in 1987 (API 1990), and an adjustment from gasoline to ethanol energy content to place the calculations in terms of the ethanol distribution industry.

Table D-7 depicts the estimates of the ethanol transport efficiencies by mode. First, the Btu-Ton-Mile values were estimated; from these values the hp-hr/10^9 Btu values were derived. In general, the Btu/Ton-Mile values were derived based on national statistics for energy consumption (MVMA 1990, EIA 1991 a, ORNL 1991, ANL 1982) and the amount of crude oil and refined products transported for each transportation mode (EIA 1991 a,b). Although the Btu/Ton-Mile values were derived for petroleum products, the same efficiencies

Table D-7.
Ethanol Transportation Mode Efficiencies

Transportation Modes	Petroleum Transport Efficiency			
	Year 2000		Year 2010	
	BTU/Ton-Mile	hp-hr/10^9 BTU	BTU/Ton-Mile	hp-hr/10^9 BTU
Pipelines/Bulk Terminals and Plants				
- Electrically-Driven Pumps (ANL 1982, ORNL 1991)	275	3270	275	3270
Rail Cars				
- Locomotives (ANL 1991)	497	1300	497	1070
Tank Trucks (Census Bureau 1990)	633	550	600	523

were assumed to apply to moving ethanol. The transportation efficiencies of BTU/Ton-Mile were generally derived by dividing the total annual national energy consumption for moving crude oil and refined products by the total national annual amount of crude oil and refined products transported by those modes in ton-miles. This method is assumed to account for specific variations in volume flow and inefficiencies in each transport mode system, and therefore represents realworld conditions. For rail, the hp-hr/10^9BTU transport efficiencies in Table D-7 represent weighted average values for the overall infrastructure. These transport efficiencies were derived from the total rail ton-miles of ethanol movements in the infrastructure in years 2000 and 2010 and the BTU/Ton-Mile value.

Since electric motor and pump technologies in the ethanol transportation infrastructure are similar for pipelines and bulk product storage facilities, the same transport efficiencies as used in pipelines were assumed for bulk product facility electric pumps. The transportation efficiencies of tank trucks were derived from fuel economy data and an assumed average product load and mileage carried by this mode. Figure D-2 lists the calculations used to estimate the modal transportation efficiencies. Figure D-3 depicts the calculations for determining the fuel and electricity inputs to the crude oil transportation system.

<u>Electricity Efficiency</u>
Assume all pipelines are electrically-driven. Also, assume the same transport efficiency used for electric pumps at bulk plants as for electrically-driven pipelines.

Total crude and refined products transported by pipeline and energy required to move the crude and refined products in 1980 (ANL 1982)
581.53 billion ton-miles
0.16 quads

BTU/ton-mile = $0.16*10^{15}/581.53*10^9 = 275.1$

Total crude and refined products transported by pipeline in 1988 (ORNL 1991)
612 billion ton-mile
992 million tons

BTU/ton = $275.1 *612*10^9/992*10^6 = 169741.3$

Applying mass energy content and BTU to hp-hr conversion:
hp-hr/10^9 BTU = 1981.9 = 1477.9 kW-h/10^9BTU

Now convert from petroleum product transfer to ethanol product transfer using ratio of fuel energy contents:
1477.9*(125,000 Btu/gal average petroleum product/75,700 Btu/gal ethanol) = 2,440.3 kWh/10^9Btu

<u>Rail</u>
497 BTU/ton-mile for all freight by rail (ANL 1991)

For year 2000, total rail mileage from Peoria to Chicago = 157

497Btu/Ton-Mile*(157 miles) = 78029 Btu/Ton

78029 Btu/Ton *(ton/2000lb)*(6.4lb/gal)*(gal/75700Btu) = 0.0033 Btu/Btu

Now convert to hp-hr/10^9Btu
0.0033 Btu/Btu = 1301.9 hp-hr/10^9Btu

For 2010, total ton-miles of ethanol transport for rail for all consumption sectors of each production site:
Peoria Site = 42151230 ton-miles
Lincoln Site = 35229810 ton-miles
Tifton Site = 40711770 ton-miles
Rochester Site = 18652920 ton-miles
Portland Site = 24985620 ton-miles
Total ton-miles = 161731350 ton-miles

497 Btu/Ton-Mile*(161731350 ton-miles)/(389.6*10^6 gal ethanol*75700Btu/gal) = 1071.2 hp-hr/10^9Btu

Figure D-2. Ethanol Transportation Mode Efficiency Calculations

Tank Truck

Assume fuel economy of 5.7 MPG for 2000 and 6.0 MPG for 2010

Assume average product load of 9,500 gallons of crude oil per haul

Year 2000

BTU/ton-mile = 137000 BTU/gal/(5.7MPG*9500gal*8lb/gal*(ton/2000lb)) = 632.5 BTU/ton-mile

Year 2010

BTU/ton-mile = 137000 BTU/gal/(6.0MPG*9500gal*8lb/gal*(ton/2000lb)) = 600.9 BTU/ton-mile

Assume average haul length for tank trucks of 50 miles

Year 2000

632.5 Btu/Ton-Mile *(50 miles) = 31625 Btu/ton

31625 Btu/Ton *(hp-hr/2544Btu)*(ton/2000lb)*(6.7lb/gal ethanol)*(gal/75700Btu) = 550.0 hp-hr/10^9Btu

Year 2010

600.9 Btu/Ton-Mile *(50 miles) = 30045 Btu/ton

30045 Btu/Ton *(hp-hr/2544Btu)*(ton/2000lb)*(6.7lb/gal ethanol)*(gal/75700Btu) = 522.6 hp-hr/10^9Btu

Figure D-2. Ethanol Transportation Mode Efficiency Calculations (Cont'd)

Electricity, No.2 Diesel Fuel

Total inputs of electricity and No.2 diesel fuel were found by weighting the transport efficiencies of the modes using each energy source as they appear in the ethanol infrastructure. Each weighted efficiency was added together to obtain a single overall weighted transportation efficiency for the modes using each energy source. Finally, to obtain total inputs of electricity and diesel fuel to the system, the total ethanol energy input to the system was applied.

The weighting of the individual transportation efficiencies was based on the assumed ethanol distribution infrastructure. A direct route from the production plant to the bulk storage plant exists for ethanol transportation, thus, no weighting of transportation efficiencies over this segment was necessary. The ethanol flow splits after the bulk plant into movements to service stations and movements to commercial accounts. The transportation efficiencies for the sources in these two branches were weighted based on estimates of current national fleet to private sector gasoline consumption (MVMA 1990).

The following method was used to find the weighted transportation efficiencies for the ethanol transportation infrastructure:

x2C = efficiencies for rail locomotives = 1301.9 hp-hr/10^9BTU in 2000
= 1071.2 hp-hr/10^9Btu in 2010

x2D = efficiencies for tank trucks = 550.0 hp-hr/10^9 BTU in 2000
= 522.6 hp-hr/10^9 BTU in 2010

x7 = efficiencies for electric pumps at bulk plants = 2440.4 kw-hr/10^9BTU

x8 = efficiencies for electric pumps at service stations = 2440.4 kw-hr/10^9BTU

x9 = efficiencies for electric pumps at commercial/rural facilities = 2440.4 kw-hr/10^9BTU

Year 2000 and 2010
WTE = x2C + x7 + 0.95*(x2D+x8) + 0.05*(x2D+x9)

Total Fuel or Electricity = WTE * Total Ethanol Energy Input in 2000 and 2010

Labor Input

Total employees in the gasoline wholesale and retail industry in 1987 (API 1990)
= 805,900

Total gasoline supplied to end-use in 1987 (API 1990)
= $2630089*10^3$ BBL = $1.275*10^{16}$ BTU

Persons/million BTU = $805900/1.275*10^{10}$ million = 0.000063

Apply ratio of ethanol to gasoline energy content of 1.52

0.000063*1.52 = 0.000096 persons/million BTU

Figure D-3. Ethanol Transportation System Calculations

D.4.2 Environmental Impact Estimates

The ethanol distribution infrastructure will produce a variety of environmental impacts. Most important among these will be air and liquid spill emissions. Assessments of each of these two types of emissions were made and are discussed below. The emission factors for the ethanol products of E10 and E95 were always derived on an incremental basis, thereby representing only the ethanol portion of the blend. A discussion of emission factor weighting also follows.

Air Emissions

Two main types of air emissions will result from ethanol distribution: exhaust and evaporative emissions. Exhaust emissions result from the combustion of fuel to move the ethanol product from production plant to end use. Therefore, assessments were made of the exhaust emissions resulting from the combustion of fuel by tank trucks and locomotives needed to transport the ethanol product. While there are exhaust emissions associated with electricity production required to operate pipeline pumps and bulk product facility pumps, assessments of these emissions were not made in this analysis but will be addressed in accompanying work.

Specific exhaust emission factors (g/bhp-hr) for HC, CO, NO_x, and particulates were derived for each major component of the ethanol distribution infrastructure based on available EPA documentation (EPA 1985 b). Differences in engine and emission control technologies for the various ethanol transportation modes for years 2000 and 2010 were accounted for in deriving the specific emission factors for each exhaust emission source for these years. Finally, using the ethanol transportation efficiencies of Table D-7, average brake specific fuel consumption values (BSFC) for each mode, and fuel combustion source density and energy content, the g/bhp-hr exhaust emission factors were converted into units of grams of pollutant emitted per thousand Btu of ethanol transported (g/10^3BTU). Figure D-4 presents the calculations used for calculating the HC, CO, NO_x, and particulate emission factors.

The CO_2 and SO_2 emission factors for the rail and tank truck modes were derived using a slightly different method than was used for the other exhaust emissions. Figure D-4 presents the calculations used for determining the CO_2 and SO_2 emission factors. The CO_2 emission factors were estimated based on fuel carbon content (87 weight percent (wt%) assumed for No. 2 diesel fuel, and 90 wt% carbon for No. 6 fuel oil), and average BSFC values. Similarly, the SO_2 emission factors were derived from fuel sulfur content (0.05 wt% sulfur assumed for No.2 diesel fuel based on current sulfur content regulations for on-highway diesel fuel), and the same brake specific fuel consumption values. It was further assumed that all of the carbon and sulfur in the fuels would be oxidized to CO_2 and SO_2, respectively, in making these calculations. Table D-8 depicts the BSFC values used in this analysis. The locomotive BSFC value was derived assuming medium speed diesel engines in these applications. All tank trucks were assumed to be powered by high speed diesel engines in determining BSFC

Calculations for HC, CO, NO_x, and particulates

$g/10^3$ Btu = (g/bhp-hr)*(1/BSFC)*(fuel density)*(1/fuel energy)*(2544Btu/hp-hr)*(transportation efficiency)

Calculations for CO_2 and SO_2
Assume use No.2 Diesel Fuel with 87 wt% carbon, and 0.05 wt% sulfur

0.87*(44lb CO_2/12lb C) = 3.2 lb CO_2/lb fuel

0.0005*(64 lb SO_2/32lb S = 0.001 lb SO_2/lb fuel

Now apply BSFC values, transportation efficiencies, and pounds to grams conversion for each mode:

For CO_2

g $CO_2/10^3$BTU = 3.2*(BSFC lb/bhp-hr)^2*(transport efficiency hp-hr/10^9BTU)*(454g/lb)*(1/BSFC)*(1/fuel energy)*(fuel density)*(2544Btu/hp-hr)

For SO_2
g $SO_2/10^3$BTU = 0.001*(BSFC lb/bhp-hr)^2*(transport efficiency hp-hr/10^9BTU)*(454g/lb)*(1/BSFC)*(1/fuel energy)*(fuel density)*(2544Btu/hp-hr)

Figure D-4. CO_2 and SO_2 Exhaust Emission Factor Calculations

Table D-8.
Brake Specific Fuel Consumption Values for Various Ethanol Distribution System Transportation Modes

Transportation Modes	Product Transport Efficiency	
	Year 2000	Year 2010
Rail Cars		
- Locomotives	0.37 lb/bhp-hr	0.37 lb/bhp-hr
Tank Trucks	0.46 lb/bhp-hr	0.44 lb/bhp-hr

values. However, unlike the other ethanol moved by rail, BSFC improvements were assumed for tank trucks for years 2000 and 2010 relative to current BSFC levels. The tank truck BSFC values were estimated by projecting 1987 national average fuel economies for tractor/trailer combinations (MVMA 1990) to years 2000 and 2010 using National Energy Strategy (NES) projections (DOE 1991), and converting to BSFC values (MVMA 1983).

The exhaust emission factors for each source of the overall ethanol transportation infrastructure for the years 2000 and 2010 are listed in Table D-9. These pollutants comprise the majority of mass exhaust emissions and are also significant due to their potential for contributions to ambient ozone formation, CO concentrations, and acid rain. The CO_2 emission factors were generally assumed to remain constant for the years 2000 and 2010 except for tank trucks. For tank trucks, improved BSFC values in 2010 result in lower CO_2 emissions in that year relative to year 2000.

The other major type of air emission from the ethanol distribution infrastructure is evaporative VOC emissions. These emissions result from the vaporization of fuel and subsequent release of these vapors to the atmosphere. Of course, evaporative VOC emissions are directly proportional to fuel volatility. Therefore, ethanol will produce much lower evaporative VOC emissions than high volatility products like gasoline. A Reid vapor pressure (RVP) of 2.3 psi was assumed for ethanol. In the ethanol distribution infrastructure, evaporative VOC emission occur from a variety of activities and processes such as during product transit between facilities, loading and unloading of product at facilities, and from bulk storage at facilities.

Evaporative VOC emission factors for the ethanol infrastructure were estimated using the EPA document, AP-42 (EPA 1985 a). The AP-42 document details the specific equations for estimating evaporative VOC emission factors for various operational practices within the petroleum distribution system. However, emission factors for ethanol were derived by inputing required values for ethanol product properties in the equations instead of gasoline or crude oil. The specific calculations for deriving the evaporative VOC emission factors for this analysis are listed in Figures D-9 through D-7.

In general, the emission factors were derived for each source of the ethanol distribution infrastructure in the 2000 and 2010 timeframes based on the characteristic source assumptions for these years. The methodology used was to first calculate "uncontrolled" evaporative VOC emission factors for each source, and then apply percentage reductions for the use of vapor control equipment such that "controlled" emission factors were obtained. The percentage reductions for specific vapor control technologies in place for each source in years 2000 and 2010 were assumed based on previously documented EPA estimates (EPA 1988 a, EPA 1989, EPA 1988 c).

Table D-9.
Estimates of Exhaust Emission Factors for Ethanol Transportation Sources

Exhaust Emission Source	Exhaust Emission Factors ($g/10^3$ Btu Throughput)											
	HC		CO		NO_x		Part		CO_2		SO_2	
	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010
Rail Cars												
- Locomotives	0.000195	0.000120	0.000487	0.000325	0.003410	0.0020	0.000073	0.000040	0.262	0.215	0.000080	0.000066
Tank Trucks	0.000165	0.000164	0.000496	0.000329	0.000629	0.000329	0.000013	0.000013	0.110	0.104	0.000034	0.000032

Transit Loss Emission Factor, L1

From AP-42 (EPA 1985 b),

Average transit loss emission factor for tank trucks with 10 RVP gasoline:

$L1 = (0.0 + 0.01)/2 = 0.005$ lb/1000gal

Assume L1 for E10 and E95 is proportional to the true vapor pressures of reformulated gasoline,

True vapor pressure of 10 RVP gasoline @ 55°F = 4.7 psi

True vapor pressure of reformulated gasoline 55°F = 4.2 psi

True vapor pressure of neat ethanol @ 55°F = 0.5 psi

Ratio of gasoline RVP 9 to RVP 10 = 4.2/4.7 = 0.894

Ratio of ethanol to gasoline RVP 10 = 0.5/4.7

For gasoline RVP 9,

$L1 = 0.894*0.005 = 0.004$ lb/10^3gal

For neat ethanol,

$L1 = 0.1064*0.005 = 0.0005$ lb/gal

For E10, transit loss equals the incremental difference between the emission factors for gasoline RVP 10 and gasoline RVP 9, plus the emission factor for neat ethanol.

$L1 = (0.005-0.004) + 0.0005 = 0.0011$ lb/10^3gal in 2000 for E10 in tank trucks

True vapor pressure of E95 equals weighted average of neat ethanol and gasoline RVP 9 true vapor pressures

True vapor pressure of E95 @ 55°F = 0.95*.5+0.05*4.2 = 0.69 psi

Ratio of E95 to RVP 9 gasoline = 0.69/4.2 = 0.16

$L1 = 0.16 * 0.005 = 0.0007$ lb/10^3gal for E95 in tank trucks in 2010

$L1 = 0.16 * 0.005 = 0.0007$ lb/10^3gal for E95 in rail cars in 2000 and 2010

Figure D-5. Evaporative VOC Calculation for Ethanol Product Transport by Rail and Tank Truck

Loading Loss Emission Factor, L2

From AP-42 (EPA 1985 b),

$$L2^* = 12.46 * \frac{(S * P * M)}{T}$$

RVP 9 Gasoline	RVP 10 Gasoline	Ethanol	E95
RVP = 9 psi	RVP = 10 psi	RVP = 2.3	RVP = 2.6
P = 4.2 psi @ 55°F	P = 4.7 psi @ 55°F	P = 0.5 @ 55°F	P = 0.7
S = 0.60	S = 0.60	S = 0.60	S = 0.60
M = 66.7 lb/lb-mole @ 60°F	M = 66.7	M = 46	M=47
T = 515°F	T =515°F	T =515°F	T = 515°F

Uncontrolled loading loss emission factor, $L2^*$ for Neat Ethanol
$L2^*$ = 0.33 lb/1000gal

Uncontrolled loading loss emission factor, $L2^*$ for RVP 10 gasoline
$L2^*$ = 4.5 lb/1000gal

Uncontrolled loading loss emission factor, $L2^*$ for RVP 9 gasoline
$L2^*$ = 4.1 lb/1000gal

Uncontrolled loading loss emission factor, $L2^*$ for E10
$L2^*$ = (4.5-4.1) + 0.33 = 0.76 lb/gal

Uncontrolled loading loss emission factor, $L2^*$ for E95
$L2^*$ = 0.48 lb/1000gal

Assume vapor control equipment for tank truck loading procedures:
Year 2000, 95% efficiency
Year 2010, 98% efficiency

Assume vapor tight cargo tank control efficiency for loading procedures:
Years 2000 and 2010, 67% efficiency

Controlled loading loss emission factor, L2 = $L2^*$ * (vapor tight cargo and control efficiencies)

Year 2000, for E10, L2 = 0.76 * (1-0.67) * (1-0.95) = 0.013 lb/1000gal for tank trucks
Year 2010, for E95, L2 = 0.48 * (1-0.67) * (1-0.95) = 0.008 lb/1000gal for tank trucks
Years 2000 and 2010, for E95, L2 = 0.48 * (1-0.67) * (1-0.95) = 0.008 lb/1000gal for tank cars

Figure D-5. Evaporative VOC Calculation for Ethanol Product Transport by Rail and Tank Truck (Cont'd)

Facility and Storage Tank Assumptions:
Each bulk plant uses 1 fixed roof storage tank
Storage tank capacity = 15,000 gallons (each)
Tank dimensions = 10.5 ft. dia. x 23 ft. high

Year 2000

In 2000 all of the ethanol is supplied by one plant at 68.2 million gallons/year output.
All of the ethanol from the plant is assumed to be consumed in the Chicago area as E10.
Ethanol to gasoline consumption ratio for Chicago area: $68.2 \times 10^6 / 921 \times 10^6 = 0.05$
where: 921×10^6 Gallons/yr is projected gasoline consumption by the Chicago population segment in 2000.
therefore: Ethanol bulk plants in Chicago will have a throughput of $(0.05)(1.7 \times 10^6) = 85{,}000$ Gal/yr of E10.

Bulk plant throughput as E10 = 85,000 gallons/year

Assume facility operates 260 days/year

Use AP-42 (equation for fixed roof tanks.

Tank Breathing Loss: $L_t = L_b + L_w$

where: L_t = Total loss

L_b = breathing loss
$= 2.26/100\ M_v\ (P/P_a\text{-}P)^{0.68}\ D^{1.73}\ H_v^{0.51}\ \Delta T^{0.50}\ F_p C K_c = 48.5$ lb/yr.
where:

$P = 0.5$ psi
$P_a = 14.7$ psi
$M_v = 46$ lb/lb-mole
$K_c = 1.0$ (for ethanol)
$D = 10.5$ ft.
$H_v = 11.5$ ft.
$\Delta T = 20$ degrees F
$F_p = 1.00$ (assume white tank)
$C = 0.5$

L_w = working loss $= 2.40 \times 10^{-5}\ M_v\ PVNK_N K_c = 47.2$ lbs./yr.
where:
$M_v = 46$ lb/lb-mole
$P = 0.5$ psi
$V = 15{,}000$ gallons
$N = 5.7$ turnovers/yr
$K_N = 1.0$ (turnover factor)
$K_c = 1.0$ (for ethanol)

Emission Factors:

Uncontrolled VOC emissions: $\mathbf{L_t = 48.54 + 47.2 = 95.7}$ **lbs/yr/**
$\mathbf{L_t = 6755}$ **g/10^9 Btu throughput for facility**

Assume 95% vapor recovery efficiency for storage tank:
$\mathbf{L_t = 338}$ **g/10^9 Btu throughput for facility**

To calculate VOC emissions from E10 at bulk plants:
$\mathbf{E10_{VOC} = E100_{VOC} + (G_{10} - G_9) = 338 + (1184 - 1062) = 460}$ **g/10^9 Btu throughput for facility**
where:
$E100_{VOC} = 338$ g/10^9 Btu throughput for an E100 bulk plant facility.
$G_{10} = 1184$ g/10^9 Btu throughput for bulk plant facility using gasoline with 10 psi RVP.
$G_9 = 1062$ g/10^9 Btu throughput for bulk plant facility using gasoline with 9 psi RVP.

Figure D-6. Evaporative VOC Calculation for Ethanol Product Storage at Bulk Plants

Year 2010

Ethanol is distributed as E95.
In 2010, ethanol is supplied by 5 ethanol plants (each producing 50 million gallons/year in 5 different geographic locations throughout the U.S.
Projected gasoline consumption in the five areas is expected to total 2.856 billion gallons/yr.
Ethanol to gasoline consumption ratio: $(5 \times 50 \times 10^6)/ (2856 \times 10^6) = 0.09$
Therefore it is expected that 9 % of bulk plant throughput will be ethanol as E95.
with a throughput of E95 = $0.09(1.7 \times 10^6)$ = 153,000 gal/yr.

Use AP-42 equation for E95 in fixed roof tanks.

Tank Breathing Loss: $L_t = L_b + L_w$

where: L_t = Total loss

L_b = breathing loss
$= 2.26/100\ M_v\ (P/P_a\text{-}P)^{0.68}\ D^{1.73}\ H_v^{0.51}\ \Delta T^{0.50}\ F_p C K_c = 62.25$ lb/yr.
where:

P = 0.685 psi (true vapor pressure of E95)
P_a = 14.7 psi
M_v = 47 lb/lb-mole (E95)
K_c = 1.0 (for ethanol)
D = 10.5 ft.
H_v = 11.5 ft.
ΔT = 20 degrees F
F_p = 1.00 (assume white tank)
C = 0.5

L_w = working loss = $2.40 \times 10^{-5}\ M_v\ PVNK_NK_c$ = 119 lbs./yr.
where:
M_v = 47 lb/lb-mole (E95)
P= 0.685 psi
V = 15,000 gallons
N = 10.2 turnovers/yr
K_N = 1.0 (turnover factor)
K_c = 1.0 (for ethanol)

Emission Factors:

Uncontrolled VOC emissions: **L_t = 62.25 + 119 = 181 lbs/yr/**
L_t= 6915 g/10^9 Btu throughput for facility

Assume 95% vapor recovery efficiency for storage tank:

L_t= 346 g/10^9 Btu throughput for facility

Figure D-6. Evaporative VOC Calculation for Ethanol Product Storage at Bulk Plants (Cont'd)

Underground Storage Tank Filling

From AP-42 (EPA 1985 b),

$$L2^{*} = 12.46 * \frac{(S * P * M)}{T}$$

RVP 9 Gasoline	RVP 10 Gasoline	Ethanol	E95
RVP = 9 psi	RVP = 10 psi	RVP = 2.3	RVP = 2.6
P = 4.2 psi @ 55°F	P = 4.7 psi @ 55°F	P = 0.5 @ 55°F	P = 0.7
S = 0.60	S = 0.60	S = 0.60 M = 47	
M = 66.7 lb/lb-mole	M = 66.7	M = 46	S = 0.60
T = 515°F	T =515°F	T =515°F	T = 515°F

Uncontrolled loading loss emission factor, $L2^{*}$ for Neat Ethanol
$L2^{*}$ = 0.33 lb/1000gal

Uncontrolled loading loss emission factor, $L2^{*}$ for RVP 10 gasoline
$L2^{*}$ = 4.5 lb/1000gal

Uncontrolled loading loss emission factor, $L2^{*}$ for RVP 9 gasoline
$L2^{*}$ = 4.1 lb/1000gal

Uncontrolled loading loss emission factor, $L2^{*}$ for E10
$L2^{*}$ = (4.5-4.1) + 0.33 = 0.76 lb/gal

Uncontrolled loading loss emission factor, $L2^{*}$ for E95
$L2^{*}$ = 0.48 lb/1000gal

Assume use of Stage 1 vapor control equipment for tank truck unloading procedures:
Year 2000 and 2010, 95% efficiency

Assume vapor tight cargo tank control efficiency for unloading procedures:
Years 2000 and 2010, 67% efficiency

Controlled loading loss emission factor, L2 = $L2^{*}$ * (vapor tight cargo and control efficiencies)

For underground service stations,
Year 2000, for E10, L2 = 0.76 * (1-0.67) * (1-0.95) = 0.013 lb/1000gal
Year 2010, for E95, L2 = 0.48 * (1-0.67) * (1-0.95) = 0.008 lb/1000gal

Figure D-7. Evaporative VOC Calculation for Ethanol Product Unloading, Storage, and Vehicle Refueling at Commercial Fleet and Retail Fueling Facilities

Underground Storage Tank Breathing Losses for Ethanol

Tank breathing emissions are based on gasoline values found in Section F.5
with corrections made for the true vapor pressures of E10 and E95.
Using AP-42:

Avg. Breathing Loss for a 10,000 gallon underground storage tank (UGST) = 1.0 lb/10^3 gallon throughput (10psi RVP gasoline)

Emission Factor:

UGST breathing loss for E100 = [(2.3 psi) / (9.0 psi)] * (0.454 g/gal) = 0.1164 g/Gal E100 or 1538 g/10^9 Btu

Year 2000
Calculation of UGST breathing loss for E10:

= 1538 * [(4.2 psi) / (4.7 psi)] = 1374 g/10^9 Btu throughput
where:
4.2 = true VP of 9 psi RVP gasoline
4.7 = true VP of 10 psi RVP gasoline

and: 1538 - 1374 = 164 g/10^9 Btu throughput
1538(0.5/4.7) = 164 g/10^9 Btu throughput
where:
0.5 = true VP of E100
4.7 = true VP of 10 psi RVP gasoline
then: = 164 + 164 = 328 g/10^9 Btu throughput

Year 2010
Calculation of UGST breathing loss for E95:

True VP of E95 = 0.95(.5) + 0.05(4.7) = 0.71 psi

(0.71/4.7) x 1538 = 232 g/10^9 Btu throughput

Figure D-7. Evaporative VOC Calculation for Ethanol Product Unloading, Storage, and Vehicle Refueling at Commercial Fleet and Retail Fueling Facilities (Cont'd)

VOC Emissions from Vehicle Refueling

Refueling Vapor Loss (g/gal) = $-5.909 - 0.0940\Delta T + 0.0084T_D + 0.485(RVP)$
where:
ΔT = fuel tank temperature - dispensed fuel temperature
fuel tank temperature = 52 F
(T_D) dispensed fuel temperature = 55 F

Year 2000
E10 Refueling Vapor Loss (g/gal)= $VOC_{E100} + (VOC_{G10} - VOC_{G9})$
where:
VOC_{E100} = refueling vapor loss of E100
VOC_{G10} = refueling vapor loss of 10 psi RVP gasoline
VOC_{G9} = refueling vapor loss of 9 psi RVP gasoline

E10 Refueling Vapor Loss (g/gal) = 0.035 + (4.1 - 3.6) = 0.85 g/gal uncontrolled vapor loss

Emission Factor:
assume 95% vapor recovery efficiency using Stage II nozzles

E10 Refueling Vapor Loss (g/gal) = 0.04 g/gal = <u>562 g/10^9 Btu throughput</u>

Year 2010
estimate E95 RVP:

E95 RVP = 0.95(2.3) + 0.05(9) = 2.2 + 0.45 = 2.7 psi RVP

Refueling Vapor Loss (g/gal) = $-5.909 - 0.0940\Delta T + 0.0084T_D + 0.485(RVP)$
where:
ΔT = fuel tank temperature - dispensed fuel temperature
fuel tank temperature = 52 F
(T_D) dispensed fuel temperature = 55 F
Emission Factor:
using equation above:
E95 refueling vapor loss = -0.765 + 0.485(2.7) = 0.54 g/gal. uncontrolled vapor loss
assuming 95% vapor recovery efficiency from stage II nozzles

E95 refueling vapor loss = 0.027 g/gal. = <u>357 g/10^9 Btu throughput</u>

Figure D-7. Evaporative VOC Calculation for Ethanol Product Unloading, Storage, and Vehicle Refueling at Commercial Fleet and Retail Fueling Facilities (Cont'd)

The evaporative VOC emission factors for each source of the ethanol distribution infrastructure are listed in Table D-10 for years 2000 and 2010. The most significant VOC emissions per Btu of ethanol throughput occur from bulk plant unloading and storage, service station and commercial account underground storage tank breathing and emptying losses, and vehicle refueling.

The evaporative VOC emissions produced from the ethanol transportation system will be comprised of ethanol as well as a variety of HC compounds due to the gasoline portion of the E10 (year 2000) and E95 (2010) blends. EPA has compiled a listing of compounds found in summer grade gasolines (EPA 1991). Many of these same HC compounds will be present in the evaporative VOC emission from E10 and E95 sources. The following are likely to comprise major portions of the E10 and E95 VOC emissions based on the EPA data: ethanol, isomers of hexanes, heptanes, octanes, nonanes, butenes, and pentanes, ethane, propane, hexane, heptane, n- and iso-butanes, 1-pentene, n-pentane, and 3-methyl pentane.

Liquid Spills

As mentioned previously, the other significant environmental emission from the ethanol distribution infrastructure is liquid spills. Liquid spills might originate from "normal operation" such as during loading and unloading episodes of transport modes at bulk facilities. For instance, a small amount of ethanol might be spilled upon hose disconnect during tank truck loading. Liquid spill data along the current gasoline distribution infrastructure for typical or "normal" operations were not available in the literature; it is assumed that these spills are typically very small and are unreported for this reason. Since spills resulting during normal ethanol distribution system operations are assumed to be small, and no representative data for such spills exists, normal operational spills are not considered for this analysis.

However, data does exist for accidental spills of gasoline. These accidental spills tend to be very significant in size. U.S. Coast Guard data (USCG 1986) was obtained for reported accidental crude oil and refined product spills in U.S. borders (200 miles (Demby 1991)). The spill data encompassed 1983 to 1987 calendar years and covered various components of the gasoline distribution system. Based on this historical data, average yearly spills rates in gallons of petroleum products were calculated. Representative spill values for the ethanol distribution sources were derived by adjusting these gasoline spill rates by the ratio of ethanol and gasoline energy contents. It was also assumed that these spill rates would apply to ethanol distribution in years 2000 and 2010, since source technology should not appreciably change to affect spill rates, and the frequency of spills is very uncertain in a given year.

To obtain liquid spill emission factors on a gram per billion Btu of ethanol throughput basis, ethanol production estimates for 2000 and 2010 were apportioned over the distribution system. The average liquid spill rates for each source were divided by the ethanol throughput for these sources to obtain the units required. Figure D-8. presents the calculations for the fuel spill emission factors for sources within the ethanol transportation system. The final ethanol spill emission factor estimates are listed in Table D-11 for each source of the distribution infrastructure in years 2000 and 2010. Note that vehicle refueling was estimated to have the highest rate of ethanol spills.

Bulk Plant Spill Rate for Ethanol
Density of neat ethanol = 2996 g/gal.
Density of reformulated gasoline = 2724 g/gal
Density of E10 = 2751 g/gal
Density of E95 = 2982 g/gal

Facility Assumptions:
Spill rate is assumed to be same as gasoline bulk plants, with corrections for the density of ethanol.
Gasoline bulk storage spill rate (as calculated in Section F.5) = 0.0248 Gal. spilled/10^9 Btu throughput or 68 g spilled/10^9 Btu throughput

Emission Factor for E10 in 2000:
Bulk Storage Spill Rate = (0.0248 Gal. spilled/10^9 Btu) (2751g/gal) *10 percent = 6.8 g spilled/10^9 Btu throughput

Emission Factor for E95 in 2010:
Bulk Storage Spill Rate = (0.0248 Gal. spilled/10^9 Btu) (2982g/gal) * 95 percent= 70 g spilled/10^9 Btu throughput

Ethanol Spills by Mode of Transport

Spill rates for ethanol transport were assumed to be the same as gasoline transport on a gallon/Btu basis as calculated in Section F.5, with corrections for the density of ethanol product.

Rail Tank Car Emission Factor for E95 in 2000 and 2010:
Rail tank car spill rate = (0.140 Gal spilled/10^9 Btu)(2982 g/gal) * .95 = 396 g spilled /10^9 Btu

Tank Truck Emission Factor for E10 in 2000:
Tank Truck spill rate = (0.190 Gal spilled/10^9 Btu)(2751 g/gal) * .10 = 52 g spilled /10^9 Btu throughput

Tank Truck Emission Factor for E95 in 2010:
Tank Truck spill rate = (0.190 Gal spilled/10^9 Btu)(2982 g/gal)*.95 = 538 g spilled /10^9 Btu throughput

Ethanol Vehicle Refueling Spills

Assume ethanol product is spilled at the same rate as gasoline on g/gal basis (EA Mueller 1989)
Gasoline is spilled at 0.23 g/gal dispensed or 1993 g/10^9 Btu dispensed
Ethanol energy content = 75,670 Btu/gal
Reformulated gasoline energy content = 115,400 Btu/gal

Emission Factor:
In 2000, for E10
Spill rate = 0.23/(75,670*.1+115400*.9)*.1 = 206 g/10^9 Btu dispensed
In 2010, for E95
Spill rate = 0.23/(75,670*.95+115400*.05)*.95 = 2961 g/10^9 Btu dispensed

Figure D-8. Calculations for Estimating Fuel Spill Emission Factors

Table D-10.
Ethanol Distribution Infrastructure Evaporative VOC Emission Factors for 2000 and 2010

SOURCE CATEGORY	VOC g/10^9 Btu throughput	
	2000	2010
Ethanol Transport		
- Rail		
- Transit	4.20	4.20
- Loading	47.9	47.9
- Tank Truck/Wagon		
- Transit	6.60	4.20
- Loading	77.9	47.9
Bulk Plant		
- Unloading & Storage	460	346
Commercial/Rural Accounts		
- UG Storage Tank Filling	77.9	47.9
- UG Storage Tank Breathing	328	232
- Vehicle Refueling	562	357
Retail Service Stations		
- UG Storage Tank Filling	77.9	77.9
- UG Storage Tank Breathing	328	232
- Vehicle Refueling	562	357

Table D-11.
Ethanol Distribution Infrastructure Liquid Spill Emission Factors for 2000 and 2010

SOURCE CATEGORY	Spills g/10^9 Btu throughput	
	2000	2010
Ethanol Transport		
- Rail	396	396
- Tank Truck/Wagon	52.0	538
Bulk Plant		
- Unloading & Storage	6.8	70.0
Commercial/Rural Accounts		
- Vehicle Refueling	206	3000
Retail Service Stations		
- Vehicle Refueling	206	3000

Weighted Emission Factors

Once each pollutant emission factor for the individual sources of the ethanol distribution infrastructure was determined, single weighted emission factors were calculated for each pollutant to represent the entire operation of the ethanol distribution infrastructure. When overall ethanol throughput over a specific period of time is applied to these overall weighted emission factor, the total mass of each pollutant emitted from ethanol distribution operations can be estimated for that same period of time.

The weighting of the individual emission factors was essentially performed based on the ethanol distribution infrastructure illustrated in Figure D-1. As shown, a direct route from the production plant to the bulk storage plant exists for ethanol transportation. Thus, no weighting over this segment was necessary. The ethanol flow splits after the bulk plant into movements to service stations and movements to commercial accounts. The emission factors for the sources in these two branches were weighted based on estimates of current national fleet to private sector gasoline consumption (MVMA 1990).

The emission factors of each leg of the ethanol distribution system were then added together to obtain overall weighted ethanol distribution emission factors for each pollutant. Figure D-9 depicts the emission factor weighting calculations for the ethanol transportation system. Tables D-12 and D-13 display the weighted emission factors for Exhaust, Evaporative VOC, and Liquid Spills for the ethanol distribution infrastructure in years 2000 and 2010.

Emission factors for each source of the infrastructure were weighted according to their position within the system. All of the weighted emission factors were then summed to obtain a single overall weighted emission factor representing the entire infrastructure.

The weighting of the individual emission factors was based on the assumed ethanol distribution infrastructure. A direct route from the production plant to the bulk storage plant exists for ethanol transportation, thus, no weighting of the emission factors over this segment was necessary. The ethanol flow splits after the bulk plant into movements to service stations and movements to commercial accounts. The emission factors for the sources in these two branches were weighted based on estimates of current national fleet to private sector gasoline consumption (MVMA 1990).

The following method was used to calculate the weighted emission factors for the ethanol transportation system:

x2C = exhaust emission factor for rail locomotives
x2D = exhaust emission factor for tank trucks

x7 = exhaust emission factor for electric pumps at bulk plants

x8 = exhaust emission factor for electric pumps at service stations

x9 = exhaust emission factor for electric pumps at commercial/rural facilities

Year 2000 and 2010
WEF = x2C + x7 + 0.95*(x2D+x8) + 0.05*(x2D+x9)

Figure D-9. Method of Emission Factor Weighting for Ethanol Transportation System

Table D-12.
Overall Weighted Emission Factors for the Ethanol Distribution Infrastructure in 2000

TRANSPORT INFRASTRUCTURE	Weighted Emission Factors (g/10^3 BTU)							
	Exhaust HC	CO	NO_x	Part	CO_2	SO_2	Evap VOC	Liquid Spills
Ethanol	0.000360	0.000983	0.00404	0.000086	0.372	0.000114	0.00156	0.000661

Table D-13.
Overall Weighted Emission Factors for the Ethanol Distribution Infrastructure in 2010

TRANSPORT INFRASTRUCTURE	Weighted Emission Factors (g/10^3 BTU)							
	Exhaust HC	CO	NO_x	Part	CO_2	SO_2	Evap VOC	Liquid Spills
Ethanol	0.000284	0.000654	0.00233	0.000053	0.319	0.000098	0.00109	0.00397

D.5 Non-Process Requirements

Several other environmental issues for ethanol distribution are discussed below:

- **Air Quality:** Certain toxic compounds of exhaust emissions are associated with ethanol distribution operations. These compounds are toxic in terms of their mutagenic or carcinogenic properties. Compounds such as benzene, formaldehyde, and 1,3 butadiene are representative of such emissions. These emissions arise from the combustion of gasoline and diesel fuel in distribution operations. While evaporative VOC emissions may contain some toxic compounds like benzene, their levels should be lower than those of current gasolines.

- **Water Resources:** Surface and groundwater resources have the potential to be affected by ethanol spills. Such effects may come in the form of bulk storage leaks, underground storage tank leaks, transportation mode transit and loading/unloading spills. Although spills occurring during normal operations can result in significant contamination of surface and groundwater resources over time, the most detrimental impacts result from large accidental spills of ethanol. A more serious impact of surface and groundwater contamination with ethanol as compared to gasoline is the water affinity of ethanol.

- **Soils:** Similar to water resources, soils would be negatively impacted from ethanol spills. The most likely sources of soil contamination from the ethanol distribution would be bulk plant storage facilities and underground storage tanks, and transit and loading/unloading spills. However, like gasoline, ethanol is biodegradable within the soil over a period of time.

- **Vegetation:** Vegetation is mainly affected from ethanol spills. Direct contamination with ethanol or indirect impacts from groundwater contamination will negatively affect vegetation. Acid rain formation as a result of certain types of fossil fuels used in electricity production for operating electric pumps in the ethanol distribution infrastructure will also have a negative impact on vegetation growth.

- **Wildlife:** Direct exposure from ethanol spills may have a damaging and immediate effect as a result of ethanol distribution operations. Another indirect impact is the loss of indigenous vegetation due to spills and acid rain. Both marine and land wildlife can be affected by spills from ethanol distribution operations.

- **Land Utilization:** Due to the ethanol infrastructure make-up as described for this analysis, the construction of additional railway spurs may be required at the ethanol plant or bulk terminal sites. The ethanol distribution routes as assumed in this analysis will be slightly different from those typically used for gasoline distribution. Additional land to lay the extra railway may be necessary to accommodate the ethanol transport infrastructure. Also, regional ethanol production level or ethanol plant site changes may require the construction of additional bulk plants.

- **Odors and Noise:** Odors and noise are proximity events. Odors and noise can result from the activities at bulk facilities and from transportation modes. Both will impact humans and wildlife which come into contact with their sources. As with the gasoline distribution infrastructure, protection can be offered to most persons employed within the ethanol distribution infrastructure in terms of respiratory and hearing protection.

- **Other Concerns:** Other environmental concerns with the ethanol distribution infrastructure are very site-specific. Certain aspects of local environments may be more susceptible to potential damage from ethanol transport than those of other areas due to differences in geology and wildlife. It is beyond the scope of this study to identify such site-specific impacts.

- **Occupational Health and Safety:** The primary occupational and safety impact on ethanol distribution system workers is the flammable properties of ethanol, and the very low flame luminosity as compared to gasoline, associated with an ethanol fire.

  While ethanol vapor has a low degree of toxicity, inhalation in high concentrations of the vapor can result in respiratory tract irritation. Skin exposure to ethanol could result in dermatitis and other skin-related problems. The ingestion of liquid ethanol is toxic and will irritate the digestive tract, and may cause nervous system depression and/or blindness.

  The Bureau of Labor Statistics reports the number of occupational injuries and illnesses associated with various industries (DOL 1990). One statistic covering the petroleum-related transportation infrastructure was injury and illness incidence rate by transportation mode. Table D-14 displays the average employment and injury and illness incident rates for pipelines (except natural gas), railroad transportation, trucking (local and long distances), water transportation, and the average private sector industry in 1988. Note that the trucking and water transportation industries exhibit higher injury and illness rates than those associated with pipelines and rail. Compared with the average private sector, only the trucking and water transportation industries had higher illness and injury rates; however, only the pipeline industry had a lower lost workday rate than the overall private sector industry average.

  Fatality rates for the ethanol distribution system are assumed to be similar to the rates in the gasoline transportation infrastructure which could be estimated from Bureau of Labor data. It should be noted that the ethanol distribution network as assumed in this analysis will use rail and highway modes of transportation in 2000 and 2010. Rates for each transport mode were assumed to be represented by the Bureau of Labor's estimate for overall transportation and public utilities. Based on this assumption, the fatality rate for the ethanol distribution modes, like gasoline distribution, is more than twice that of overall private industry.

Table D-14.
Occupational Health and Safety Projection to 2000 and 2010 for the Ethanol Distribution System

	SIC Code	Injury and Illness Rate per 100 Full-Time Workers	Lost Workdays Cases per 100 Full-Time Workers	Fatalities per 100,000 Full-Time Workers[1]
Pipeline, except natural gas	46	3.6	1.4	13.5
Railroad	40	6.9	4.9	13.5
Trucking, local and long distance	421	13.9	8.0	13.5
Water transportation	44	12.2	7.5	13.5
Average private Sector Industry		8.6	4.0	5.0

[1] Value based on overall transportation and public utilities

D.6 Pre- and Post-Operational Phases of the Ethanol Transportation Infrastructure

The hypothetical ethanol transportation infrastructure which was identified in this analysis for the years 2000 and 2010 was made-up of bulk plants, rail tank cars, tank trucks, and retail and commercial/rural facilities. This section will identify the "inputs" and "outputs" required by the ethanol transportation infrastructure from a pre-operational (before transport) and post-operational (after transport) perspective. As a result of the outputs associated with each phase, a brief description of the possible environmental impacts of each phase will be given. The pre- and post-operational phases were presented in two segments: the transportation of ethanol product by rail and highway, and the storage of ethanol product at bulk plants, retail outlets, and commercial/rural facilities.

D.6.1 Pre-Operational Phase

The two scenarios considered for this analysis, i.e. year 2000 and 2010, assumed a simple ethanol transportation infrastructure consisting of bulk plants, rail and tank truck transport, and retail and commercial fueling facilities. The following describes the pre-operational phase for transporting ethanol product via rail tank cars, and highway tank trucks.

The inputs required to construct ethanol product tank cars and tank trucks will include materials (mostly steel), energy (fossil fuel/electricity), labor, and manufacturing equipment. Tank cars and tank trucks are usually manufactured at a facility specifically designed to produce this type of vehicle. The outputs associated with constructing these liquid cargo transports will be outputs emitted from the factory or facility that produces this type of vehicle. The outputs from these facilities will include solid waste in the form of scrap materials leftover from the vehicle manufacturing processes. Air outputs from the factory could include fossil fuel combustion emissions depending on the design of the factory, i.e. what equipment within the factory uses fossil fuel, and what equipment is electrically powered. Liquid emissions from the factory may include any solvents or chemicals used by the factory during the manufacturing process. It is expected that the air and liquid emissions from this type of manufacturing process would have a greater impact on the surrounding environment than solid waste emissions. The environmental impact as a result of these factory emissions will depend on the geographic location of the factory and the facilities age. Outputs from factories located near inland or coastal waterways could impact both the marine and land environment. Any hazardous or toxic air or liquid emissions as a byproduct of the manufacturing processes could effect both marine and land ecosystems if not controlled. It is expected that relatively new manufacturing facilities are likely to be designed so as to minimize their possible environmental impacts from air, liquid and solid waste emissions.

The ethanol transportation infrastructure as considered in this analysis includes the storage of ethanol product at bulk plants, retail outlets, and commercial/rural facilities. Each of the storage facility inputs required for the pre-operational phase will vary, but can be summarized as requiring land, materials, labor, and fuel. Bulk plants will need storage tanks, piping and tank truck loading racks constructed. Retail ethanol product outlets will need underground storage tanks with accompanying piping and fuel dispensers. It is expected that most of the commercial and rural facilities will employ underground storage tanks to store their ethanol product inventory, and use fuel dispensers similar to those used at retail outlets. In summary, the outputs of constructing the ethanol transportation and storage segments of the ethanol infrastructure will include air emissions from construction equipment operation, liquid emissions from fuel or chemical spills during construction, and solid waste in the form of scrap building materials leftover from the construction process. In general, the specific environmental impacts of constructing the ethanol infrastructure will vary based on the geographic location and the type of facility constructed.

D.6.2 Post-Operational Phase

The post operational phase of the ethanol infrastructure includes removing tank trucks, rail tank cars, bulk plants, retail outlets, and commercial/rural facilities from service. Taking these segments of the infrastructure out of service will require complete or partial disassembly of the liquid tank carriers, and bulk storage facilities etc.. After the disassembly is complete, recycling the materials (steel) or salvaging them for further use in other parts of the ethanol infrastructure are likely possibilities. In order to decommission the transport and storage segments of the ethanol infrastructure several inputs will be needed. There will be inputs of fuel, labor, and land for the post-operational phase of the ethanol infrastructure. It is expected that heavy equipment powered by diesel fuel will be used to disassemble the vehicles and facilities described above. There will be possible air, liquid, and solid waste emissions from the clean-up operations, as well as land reclamation of sites once all of the facility and equipment has been removed. Soil erosion is a possible impact once the storage facility structure has been removed from the site. In summary the environmental impacts of decommissioning each segment of the ethanol infrastructure will vary depending on the geographic location of the bulk plant, retail outlet, or commercial/rural facility.

D.7 Discussion and Summary

In this study, ethanol fuel was assumed to be produced in five locations around the country. These included Peoria, Illinois, Lincoln, Nebraska, Tifton, Georgia, Rochester, New York, and Portland, Oregon. In the year 2000, E95 was assumed to be produced in Peoria only (by blending ethanol and reformulated gasoline), all of which was sent to Chicago area bulk plants to be blended further with reformulated gasoline and consumed in Chicago as E10. In the year 2010, all five sites were assumed to produce E95 to be consumed as E95 in a number of regional consumption sectors. The 2010 E95 consumption sectors were determined for each production site by including only those major urban areas within 200 miles the plant and with populations of 50,000 or more. (The locations of the plants were also assumed to consume some portion of E95.) The ethanol production in 2010 for each site was distributed among the consumption sectors based on their populations.

An ethanol distribution infrastructure consisting of direct transfer of E95 from production plant to bulk plants for each of the five sites was assumed due to the level of ethanol production relative to typical gasoline refinery production. After inspection of potential transport modes for this segment of the ethanol distribution system in each site, rail car was assumed to be the primary mode for this segment. After required blending to E10 in year 2000 at the bulk plants, the ethanol product was assumed to be transported to service stations and commercial accounts via tank trucks.

The inputs of the ethanol transport process were characterized as ethanol, No. 2 diesel fuel, electricity, replacement parts, and labor. The energy output of the system consisted only of ethanol.

The main environmental impacts of the ethanol distribution infrastructure system were characterized as air and liquid spill emissions. The air emissions consist of both exhaust and evaporative emissions. The exhaust emissions result from the combustion of fuel for transporting the crude through the infrastructure to the refinery. Specific exhaust emission factors for HC, CO, NO_x, particulates, and CO_2 were derived for the tank truck and rail car transportation modes for years 2000 and 2010. Assessments were also made of the same exhaust emissions from electricity production required to operate bulk facility pumps.

Another important air emission from the ethanol product distribution system is evaporative VOC emissions. Such emissions result from the vaporization of fuel and the subsequent release of these vapors to the atmosphere. Evaporative VOC emissions could be released at a variety of points along the ethanol distribution infrastructure including during transit between facilities, during loading and unloading at facilities, and from bulk storage at facilities. Estimates of evaporative VOC emission factors for various transport modes and facilities of the ethanol distribution system were derived from EPA sources for years 2000 and 2010 assuming the application of various types of vapor control equipment for these modes and facilities in these years.

The other main environmental impact of ethanol product transportation comes in the form of liquid spills. Such spills may originate from "normal" operations, such from loading hose disconnect, or from accidental occurrences. Industry data on "normal" operations was not available. It was also assumed that such spills would be small and insignificant relative to accidental spills. Therefore, emission factors for "normal" operational spills of ethanol were not estimated.

However, historical data was available for accidental spills for the transportation modes and bulk storage facilities of the current petroleum transportation system. Based on this data, estimates of annual accidental spill rates along the ethanol transportation infrastructure system were determined for years 2000 and 2010.

Once the exhaust, evaporative VOC, and liquid spill emission factors for individual components of the ethanol transportation system were derived, they were weighted based on total system throughput in order to estimate a single emission factor for each pollutant representing ethanol transport. The weighting was performed for the amount of ethanol assumed to flow through each segment of the distribution system.

Table D-15 summarizes the total inputs and outputs of the ethanol transportation system for years 2000 and 2010. It should be noted that these inputs and outputs were derived incrementally for the ethanol portion of the ethanol product only. The per year estimates were derived by applying the assumed ethanol production numbers for 2000 and 2010 to the weighted system inputs and emission outputs. It was assumed that ethanol production was equivalent to ethanol throughput to final end-use.

Table D-15.
Summary of Total Inputs and Outputs for Ethanol Distribution Infrastructure in 2000 and 2010

	2000		2010	
	per MMBTU	per Year	per MMBTU	per Year
INPUTS				
Ethanol (bbl)	0.315	1,620,000	0.315	9,280,000
No. 2 Diesel Fuel (bbl)	0.000872	4,500	0.000749	22,100
Electricity (kWh)	4.88	25,200,000	4.88	144,000,000
Labor (persons)	0.000096	496	0.000096	2,830
Replacement Parts	N/A[1]	N/A	N/A	N/A
OUTPUTS				
Ethanol (bbl)	0.315	1,620,000	0.315	9,280,000
Air Emissions (lbs,tons)				
HC	0.000794	2.05	0.000625	9.22
CO	0.00217	5.59	0.00144	21.2
NO_x	0.00891	23.0	0.00513	75.7
Particulates	0.000190	0.490	0.000117	1.73
SO_2	0.000251	0.648	0.000216	3.18
CO_2	0.821	2,120	0.705	10,400
Total Evaporative VOC	0.00345	8.90	0.00239	35.3
Liquid Spill Emissions (lbs,tons)	0.00146	3.76	0.00875	129

[1] N/A = Not Available

D.8 References

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